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A Study of the Feasibility of Employing a Magnetic Mass Spectrometer for the Analysis of the Martian Atmosphere

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Prepared for the
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Abstract:

A study of magnetic-sector mass spectrometers has been conducted to test the feasibility of employing such instruments for making analyses of planetary atmospheres. A number of designs of spectrometers were tried, as were appropriate transistorized electronic circuits. A preliminary study of a miniature sputter ion pump was also carried out.

The investigations showed that essentially all but the weight specification given in SW-2751 could be met. It is likely that further studies will result in weight reductions. This would certainly be the case if a reconsideration of the entire problem showed that some of the other specifications could be modified.

I. STATEMENT OF THE PROBLEM

This is a report on a study program initiated to examine the practicality of employing a magnetic sector mass spectrometer for determining the composition of a planetary atmosphere such as one might find on Mars. In undertaking the study, the work statement provided by the Jet Propulsion Laboratory (SW-2751, January 12, 1962) was used as a guide. This statement gave certain parameters relating to the atmosphere to be expected, the performance of the instrument and technical requirements. These specifications, together with an additional one, are enumerated below and will be commented on later in the present report.

A. Assumed Martian Atmosphere Model

1. Atmospheric pressure at the surface of Mars:
   40 mb P_s 140 mb

2. Composition of atmosphere (volume %)

0	H_2O	0.1% (vapor)
0	N_2	100%
0	CO_2	15%
0	O_2	10%
0	Ar	20%

3. Temperature at surface: 200°K T 300°K

4. Density at the surface: 4.6×10^{-5} gm/cm^3 $< \rho_s <$ 2.4×10^{-4} gm/cm^3

5. Probable sampling limits:
   P sp = 15 mb to 140 mb
   Tsp = 150°K to 300°K
   sp = 3.5×10^{-5} gm/cm^3 to 2.4×10^{-4} gm/cm^3

6. Change in composition over sampling limits will be negligible with the possible exception of H_2O.

B. Relevant data obtained from other experiments.

1. Continuous pressure measurements.
2. Continuous temperature measurements.
3. Altitude measurements.

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C. Sampling condition.

1. One or more discrete or continuous samples of the Martian atmosphere will be analyzed.

2. Sampling will be from a dynamic system with the gas flowing past the capsule at a rate of 50 to 150 feet per second.

3. Maximum analysis plus data-transmission time will be no more than 20 minutes and no less than 5 minutes.

D. Mass Spectrometer operating parameters shall be such that it shall operate uniformly over the full analysis period (~20 minutes) implying that a sufficient vacuum in the system is maintained throughout the transit time of approximately six (6) months and during the analysis time.

E. Technical requirements.

1. Weight - the weight of the entire experiment (including associated electronics) shall not exceed five (5) pounds.

2. Volume - 800 cubic centimeters per pound maximum.

3. Configuration - rectangular box.

4. Sensitivity - ability to detect at least 0.1 volume per cent components.

5. Accuracy - $\pm$ 10% on 1% components; $\pm$ 5% or better on 80% components.

6. Resolution -

$$\left.\frac{M}{\Delta M}\right)_{1\%} = 25 \text{ or better}$$

7. Mass Range - 12-50 amu

8. Spectrum scanning time per sample shall be 20 to 60 seconds.

9. Nominal power requirements:

a. Not to exceed six (6) watts during operation.

b. Voltage and wave form of power required may be suggested by contractor. Power available from spacecraft is as follows:

(i) 28V DC - used primarily for operating relays and small motors.*

(ii) 2400 cps, 50V peak (100V p to p) square wave. Rise and fall times 30 microseconds. Voltage regulation: $\pm$ 2% generally used in scientific transformer-rectifier units to produce DC voltages and as basic "clock".

(iii) 26V rms, 400 cps, 3 phase sinusoidal wave - primarily used for motors.

*We understand that this power or equivalent is to be used for operating our electronics.

10. Output signal - 0 to +5 volts.

11. Sampling Constraints

    a. One or more samples shall be analyzed dependent on gas load tolerances of system which is governed by inlet system conductance and pump capacity.

    b. Sampling representative of the Martian atmosphere is required.

12. Stray magnetic field of instrument at distance of 3 feet should be less than 1 γ. (This specification was not in original work statement.)

II. STUDY PROGRAM UNDERTAKEN

Although magnetic sector mass spectrometers have demonstrated their value in the laboratory--indeed, are the most common type used--they have not generally been considered appropriate for space investigations. This attitude probably stems primarily from two considerations: (1) A magnet is employed and magnets are thought of as being heavy; thus the instrument must necessarily be heavy, and (2) because the mass spectrometer must share a place with other instruments in a space vehicle, particularly magnetometers, the stray magnetic field may interfere with the operation of such other instruments.

While these points have merit, they tend to ignore the fact that a magnetic sector instrument is extremely simple electronically as well as being compact, and as a result, the overall weight and power consumption may be comparable with that of alternative types of instruments. Also, with a properly designed magnet, the stray field may be low and hence not objectionable.

A consideration not taken into account is the important fact that in all likelihood some type of a pump will have to be employed to hold the pressure in the instrument to a low value while the capsule descends into the planetary atmosphere. Of the various pumps which one can consider,

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some type of a getter or sputter pump seems most promising. To our knowledge, no one has developed a successful sputter pump which does not employ a magnet. All commercially available pumps employ rather heavy magnets having extremely high stray fields. Thus if a separate ion sputter pump were to be employed with a non-magnetic mass spectrometer, most, if not all, obvious advantages of the non-magnetic instrument would be lost. Under the circumstances, the attractive possibility of using for an ion sputter pump the well-shielded magnet already available in the magnetic spectrometer would appear well worth investigating in some detail.

The remainder of this report will describe (1) experiments undertaken to test various components, (2) a proposed design based on information available as of the time of preparing the report, (3) performance characteristics to be expected from the proposed design, (4) power, weight and other parameters to be expected, and (5) recommendations on further studies.

A. <u>Investigation of magnetic sector instruments.</u>

1. A 90° deflection, 2-inch radius instrument.

On the basis of previous experience with a 60° two-inch instrument, it was realized that an instrument having a radius of curvature of two inches in the magnetic field would almost certainly be too heavy to meet the specifications for the present program. On the other hand, in view of the extremely tight time schedule for the program and the inability to obtain Alnico of proper dimensions in a reasonable time, it was felt best to construct a two-inch, 90° instrument using materials on hand. Such a study would enable one to check the stray field properties of the magnet design proposed and to construct an instrument which would serve as a facility for testing various components as the program progressed. The 90° rather than 60° instrument was constructed in order to gain experience with a design slightly different from that previously studied.[1]

Fig. 1 is a schematic drawing of the mass spectrometer tube. The source and collector housings were turned from type 303 stainless steel. The flattened analyzer tube was formed[2] from 0.500" O.D., 0.020" wall, type 303 stainless steel tubing and hard-soldered to the source and collector housings. The source and collectors were mounted on flanges and inserted as indicated. By means of the pump lead shown, the tube could be attached to a manifold for evacuation and admission of gas. The tube, together with its magnet, is mounted on an aluminum plate. Fig. 2 is a photograph showing the mounted spectrometer tube. The magnet is in place. The end shield plates on the magnet have been removed to make it possible to see the magnet poles and the flattened portion of the magnetic analyzer. Fig. 3 shows the shield plates in place. Their role in reducing the stray magnetic field will be discussed more fully in connection with the 60° 1.5-inch instrument. In both these figures, the ion source and collector assemblies have been removed.

Figures 4A, 4B and 4C give the details of the ion source referred to in Fig. 1 and used in all the tests to be described in this report. In summary, it can be said to resemble ion sources used in the past in this laboratory. The glass ball insulators provide a rugged construction which will survive vibration and drop tests. The hairpin filament made of 0.003" tungsten wire consumes only 1.3 watts. Since the hairpin shape minimized the forces produced by the magnetic collimating field, the power can be supplied by an alternating current source with the

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result that one can diminate the power loss which would result if a converter to direct current had to be supplied.

Figure 5 is a photograph of the ion source. The source used here was constructed with the thought of having maximum flexibility so that one might readily make changes in order to try different designs. In a flight model one obviously would not have the heavy flange shown, and every effort would be made to reduce weight.

The ion collector assembly also was mounted on a flange, and the construction followed closely that employed for the source. Fig. 6 gives the details. As for the source, the general arrangement follows that employed for some years in this laboratory. Obviously in a flight model, the weight could be reduced drastically. Fig. 7 is a photograph. One of the two electrical leads is for the collector itself, the other for an electron repeller plate in front of the collector. When supplied with a negative potential, this plate prevents secondary electrons emitted from the collector or the defining slit in front of it from interfering with the reading of the ion currents to the collector.

Fig. 8 is a spectrum obtained when air at a pressure of 5×10^{-6} is present in the tube. It is seen that the sensitivity and resolution are sufficient to detect rare components. For example, the $O^{16}O^{18}$ ion appearing at mass 34 and having an abundance of 1/250 of the $O^{16}O^{16}$ peak at mass 32 is clearly visible. Also while the $N^{15}N^{14}$ peak appearing at mass 29 and having an abundance of approximately 1/135 of the $N^{14}N^{14}$ peak at mass 28 is not completely resolved, it is clearly below the one percent level set in the specifications for ions in this general mass range. In this particular test, the instrument had not been baked particularly well, and stray residual peaks were present. These can be seen in the region around argon (mass 40) and at 30. During these tests, the CO_2 residual (mass 44) also was somewhat higher than normal. Since the instrument employs a permanent magnet, mass spectra are obtained by continuously changing the ion accelerating voltage. For the magnet used, the field strength in the gap was 2800 gauss. Hence with the 2-inch radius, the 28 peak is focused for an ion accelerating potential of 365 volts. The mass collected is inversely proportional to ion accelerating voltage. The various spectra shown in this report were obtained by sweeping the voltage at a rather slow rate with a motor-driven potentiometer. This slow rate (approximately 3 minutes for a spectrum) was adopted merely to make certain that the relatively slow recorder employed would respond, and also to make it convenient to switch amplifier sensitvity to appropriate values at different points along the spectrum. The amplifiers employed have sufficiently good time response to permit spectral sweeps in as short a period as a few seconds.[1] For the Martian flight we would recommend a spectral sweep time of perhaps five or ten seconds.

Although the 2-inch 90-degree instrument described here would more than meet the performance specifications, it was abandoned as too heavy to meet the weight specifications. The shielded magnet weighed 54 ounces. Even so, the magnet yoke was only 0.125 inches thick, and the shield plates 0.065 inches thick. With these thicknesses, the stray magnetic field was far too large to meet the specifications. An increase to a suitable wall thickness would have increased the weight considerably. Thus the 2-inch-size instrument was abandoned in favor of a 1.5 inch model.

2. A 90° deflection, 1.5-inch-radius instrument.

The tests on the 90° deflection, 2-inch-radius instruments showed clearly that one did not need to construct an instrument as large as this. Hopefully, by cutting the size one could reduce the weight sufficiently to meet the weight specifications without making too great a sacrifice in performance. Thus the next spectrometer tube tested employed 90° deflection with a 1.5-inch trajectory radius. The source and collector housings were identical with those for the 2-inch instrument, and the same source and collector were employed. Thus the appearance of the tube was the same as shown in the schematic drawing of Fig. 1 and the photograph of Fig. 2. Details of the magnet will be discussed in the section dealing with the 60° deflection, 1.5-inch-radius instrument.

Fig. 9 shows the spectrum obtained when air at a pressure of 5×10^{-6} was present in the tube. In comparing the spectrum with that found for the 90°, 2-inch tube (Fig. 8) one sees that the resolution clearly is less. This is to be expected since the same source and collector were employed as before, and the slits were not changed. The dispersion is directly proportional to the radius of the instrument. Nevertheless the resolution and sensitivity in the smaller instrument are adequate to meet the specifications of the problem. Because of the more efficient magnet yoke employed in the 1.5-inch instruments tested, the field strength in the air gap, 3540 gauss, was larger than in the 2-inch instrument. Thus the 28 peak was collected when the ion accelerating voltage was 310 volts.

3. A 60° deflection, 1.5-inch-radius instrument.

Although in principal the resolution and performance of a magnetic sector instrument should be independent of the magnet sector angle, the smaller the angle the greater the proportion of the trajectory which is in the non-uniform field at the entrance and exit regions. Also because of the theorem showing that the source slit, apex of magnet sector, and collector slit all lie on a straight line in order to obtain first order direction focusing, the smaller the angle the further apart will be the source and collector, and consequently the less compact will be the instrument. Balanced against these adverse factors is the important consideration that a large part of the weight of the total instrument is in the main deflecting magnet, and the smaller the angle the less will be the weight of the magnet. As a matter of fact, except for the end shields used to reduce the stray field, the weight of the magnet is almost directly proportional to the deflection angle. In view of these considerations it was decided to construct a 60° deflection, 1.5-inch-radius instrument. Again the housing of the spectrometer tube resembled those used in the earlier tests, and the same source and collector assemblies were employed.

Fig. 10 is a schematic drawing of the 60°, 1.5-inch-radius instrument. Fig. 11 is a photograph showing the tube complete with magnet and mounted on its aluminum base plate and connected to the pump stand. The orientation of the tube corresponds to that in Fig. 10. This photograph also shows a portion of the test stand employed for the studies reported here. The large valve block toward the lower left hand corner of the picture permits connecting the spectrometer tube to various pumps and also serves as a manifold for admitting air or other gases.

Fig. 12 is a spectrum obtained when air at a pressure of 5×10^{-6} torr is present. It is seen that the resolution is inferior to that found for the 90°, 1.5-inch instrument. Nevertheless the resolution appears to meet the specification of having the background down to one percent of a peak height when one moves one mass unit away from a peak in the region of mass 25. The sensitivity of the instrument is such that with the pressure of 5×10^{-6} torr in the source, the 28 peak in air has an intensity of approximately 5×10^{-10} amperes. Since the amplifiers employed have a noise level of 10^{-13} amperes or better when a 10^{10} ohm input resistor is used, one clearly could narrow the slits and thus improve the resolution and still meet the sensitivity specification of 0.1%. The present tests were all conducted at a source pressure of 5×10^{-6} torr. One can readily operate the source at 5 or 10 times the pressure, especially if a differential pumping system is employed between source and analyzer regions. It thus appears that a 60°, 1.5-inch or even smaller instrument can meet the resolution and sensitivity requirements.

The remainder of the present report will assume that this is the type of instrument which will be employed in further studies. If subsequent considerations point to the desirability of changing the size or geometry, it will be a relatively simple matter to make such changes.

B. Main deflection magnet

Figure 13 is a drawing showing details of construction of the deflection magnet employed in the 60°, 1.5-inch instrument. The magnet poles were cut from Alnico V rings and the yoke turned from Armco iron. A photograph of the assembled magnet is shown in Fig. 14. The end shields which aid materially in the reduction of the stray field are shown at the sides of the magnet. With the shields in place, the stray field has its maximum value on the lines from magnet to source or collector. At 3.5 feet, this value is approximately 1.3 gammas as measured with a rubidium magnetometer. Without the shield plates, the value is approximately 500 gammas.

The magnet without shield plates weighed 26 ounces. The weight of the four shield plates was 10.5 ounces. Thus the total weight of the

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magnet assembly was 36.5 ounces = 2.3 pounds. It would be worth examining the design of the magnet to see if the weight could be cut without reducing the field in the gap or increasing the stray field.

C. Electronic Circuits

In order to carry on the tests described in the present report, a set of electronic circuits was constructed. In part, these were direct copies of circuits employed for other applications in the laboratory; in part they were circuits which would also serve to test new developments which might be applicable to the problem at hand. In some cases, an effort was made to reduce the power consumption to a minimum in recognition of the fact that this would be a serious problem in the ultimate design. In no case was any effort made to reduce weight (except for certain components undergoing test), and units were mounted on standard relay rack size chassis or panels. All units operated from 12V DC power sources. This voltage happens to be the one chosen in our laboratory as the input potential for transistorized amplifiers, high voltage power supplies, etc. The units could just as well have operated from a 28 volt source if the power transformers had different windings. In a breadboard model, this change would be made.

1. Electronic Amplifier

Fig. 15A is a schematic diagram of the high-gain inverse-feedback electrometer tube amplifier used in all the tests. As an input stage, a pair of CK5889* electrometer tubes are used in a differential circuit. The remainder of the circuit is transistorized. The gain of approximately 8,000 insures both a high degree of linearity and a fast time response. The large dynamic range permits handling of signals as large as 50 volts. On the other hand, the background noise is less than one millivolt so

*Tube replacing obsolete CK5886 shown in circuit diagram.

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one can detect relatively small signals. The total power consumption of the amplifier is approximately one watt. Numerous amplifiers of this design have been used in our laboratory for the past few years, and two were employed in a mass spectrometer sent into the upper atmosphere with an Aerobee-Hi rocket last spring. Although the shot was a failure for other reasons, the amplifiers functioned perfectly. With a 10^{10} ohm input resistor, the time response was sufficiently fast to permit a scan over the mass range 12 to 50 every two seconds.

2. Ion Acceleration Supply

Fig. 15B shows the circuit for a laboratory power supply used for accelerating ions. The output voltage is adjustable and covers the range 200 to 1,000 volts. Taps are provided for the focusing electrodes, J_1 and J_2. There is also provision for the plates of an electrostatic analyzer if one wishes to test double-focusing instruments such as the one earlier described(1). By means of a motor-driven potentiometer, spectra can be scanned slowly as in Figures 8, 9 and 12. Fast sweeps can be obtained with the condenser discharge sweep arrangement shown.

Fig. 15D is a circuit for a high voltage supply which gives an output voltage which varies between 1,000 and 200 volts with a time constant determined by the condenser chosen. Repetition is automatic. No relays are required. A unit similar to this could be employed for actual flights. The base drive, (x - y), is obtained from another unit such as from Fig. 15E.

3. Electron Emission Regulator

Fig. 15C is a schematic diagram of an emission regulator employed in most of the laboratory tests. In addition to holding the emission constant by providing a regulated current to the spectrometer filament, this unit also furnishes voltages for accelerating the electrons, for trapping them in the electron trap and for repelling the ions from the ionizing region. While this unit consumes only 6.7 watts when heating a 3 mil tungsten wire filament, we do not consider this to be a high efficiency unit. It was intended only for laboratory use.

Fig. 15E is a diagram of an emission regulator unit which has a considerably higher efficiency than the one just discussed. It, too, provides potentials for the electrons and the ion repeller. The total power input for this unit, together with the ion accelerating supply of Fig. 15D, is 2.9 watts. These circuits clearly are worth considering for adoption.

D. Gas Sampling and Pumping System

According to the specifications given, one should expect the Martian atmosphere to contain essentially the same constituents as our own atmosphere, but in abundances which may be somewhat different. In any event, one should prepare to find a mixture of chemically reactive gases such as oxygen or nitrogen and inert gases such as argon. This places severe limitations on the kind of pumping system which can be employed.

One possibility which suggests itself is not to employ any pump at all. Instead, in planning for the analysis, one might consider the following sequence: (1) evacuate and seal spectrometer before it leaves earth; (2) open to space during journey to Mars--this will keep it evacuated; (3) close just before entry to Martian atmosphere; (4) allow a definite amount of the atmosphere to enter the spectrometer through a metering system; (5) make analysis using the mass spectrometer statically

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and; (6) telemeter data to bus.

While in principle this system should work, it places severe restrictions on parts of the system. For example, the metering system must be very precise. Too large a sample would flood the spectrometer; too small a sample would result in loss of sensitivity. Also the sampling must be done at the correct time—one has only one opportunity. Further, the volume of the spectrometer tube should be as large as possible in order that the sample may be correspondingly large. Even with a spectrometer volume as large as 1 liter, the amount of gas required to give a pressure of 10^{-5} torr would be only approximately 10^{-5} cc at NTP. It is doubtful that the volume could be increased much above this value without increasing the weight by an objectionable amount.

If the spectrometer is to be run dynamically, a pumping system must be employed. The likely presence of both active and inert gases makes an ion sputter pump appear attractive. Even so, the pumping speed for inert gases is far below that of the active ones. This difference in pumping speeds can be compensated for in part by pumping on the magnetic analyzer and having a very small slit separating the ion source and analyzer region. Even this may not be too helpful since it is doubtful that the weight and stray magnetic field restrictions will permit the use of a sputter pump which has a speed of more than a few tenths of a liter per second for a gas such as nitrogen. Nevertheless sputter pumps have features such as low power consumption and simplicity, which make them very attractive to us in this program.

Unfortunately there is no commercial product available today which would meet the weight and stray magnetic field specifications of the problem. Thus we considered it worthwhile to look into the possibility of designing a sputter pump which might make use of the magnet already present as an integral part of our apparatus. The field in the air gap of our test magnet is 3500 gauss. As can be seen in Fig. 13, without pole faces there is a gap of 0.373 inches, which may be sufficient for a sputter pump. If in the construction of the magnet, one cut the poles from an Alnico ring having a smaller inside diameter than employed here and employed pole faces no wider--or even narrower--than in the present design, there would be next to the main gap an air gap of 0.373 inches. The field would be approximately 2000 gauss. While this magnetic field would have sufficient strength to operate a sputter pump (commercial pumps employ 1300 gauss, or thereabouts), it is not certain one could design a cell structure which would give a reasonable pumping speed and also permit the pump to function over a large pressure range.

To examine the feasibility of employing a pump which would make use of our magnet, a test pump was constructed. The details are shown in Fig. 16. The anode and cathode structure would fit into the magnet gap anticipated. This structure, mounted on a flange, is shown on the right side of the photograph, Fig. 17. The left side shows the housing used for the tests. The pump was mounted to the same valve manifold block as the spectrometer (see Fig. 11). Thus one could connect the pump in parallel with the mercury diffusion used for evacuating the spectrometer and compare the pressure reading of the Veeco ion gauge on the mercury pump with the current drawn by the sputter pump. In these tests the sputter pump received its power from a Varian type 921-0011 power supply whose output voltage is 3400 volts. An electromagnet, not shown in Fig. 11 provided the magnetic field.

Fig. 18 shows that the response was linear up to a pressure of at least 5×10^{-5} torr. The apparent departure from linearity for pressures above 5×10^{-5} torr is believed due to outgassing of the pump It had not been properly baked before the tests. At the lowest pressures (3×10^{-8} torr) reached during the tests the pump remained in operation. Clearly, performance at the high and low points will have to be investigated further.

The use of the manifold block permitted one to shut off the mercury diffusion pump and observe the effect on the spectra obtained. With both pumps in parallel and the air flow set to give a pressure reading of 2×10^{-6} torr in the mercury pump line (this was also approximately the pressure in the ion source) one obtains a spectrum similar to that of Fig. 12, but of course less intense due to the lower pressure. If now the valve to the mercury diffusion pump is closed, the 28 peak (N_2^+) increases in intensity by a factor of approximately 8. The mercury pump system was estimated to have a speed of approximately 5 liters/sec. Thus the sputter pump appears to have a speed of approximately 0.6 liters/sec. On the other hand, the O_2^+ rose by a factor of only 1.9, and the 40 peak (Ar^+) by a factor of 75. The behavior for Ar is not surprising; the pumping speed for oxygen may be somewhat higher than generally observed for sputter pumps. Although the results were reproducible, we are not certain that the valving system may not have introduced some systematic errors in the measurements. Such errors, if present, would only affect the numbers obtained. Qualitatively, the results would not change.

It is clear from these tests, as well as from previous knowledge, that if a sputter pump is to be employed, and one wishes to obtain reasonably quantitative information, the pumping speed for the several gases should be determined primarily by an aperture rather than by the pump. This condition could be met by making the pump part of the analyzer housing and by separating the ion source region from the analyzer. The only passage between the two regions would be the slit in G_1 which defines the ion beam. At some expense of sensitivity, the slit could be made both shorter and narrower than in the tests performed to date. If this slit were cut to 0.004" x 0.08", it would have a pumping speed of 0.02 liters/sec. for air. Offhand, it appears doubtful that in an actual flight model meeting the weight specifications, one could employ a pump having as large an anode structure as used in these tests. Perhaps half the size would be reasonable. Thus one might reasonably expect a pumping speed for N_2 of 0.2 to 0.3 liters/sec. This would not be enough more than the speed of the aperture to make the overall pumping speed of the system truly independent of the discrimination effects of the sputter pump. While one arbitrarily could apply correction factors based on laboratory tests for the various constituents expected, it is likely that the calibrations would depend upon the previous history of the pump and hence one could not rely on them. Hence it may be unrealistic to hope for full achievement of the precision of analysis stated in the specifications for the problem.

Because of the severe limitations in time it was not practical to work on the gas admission system. Nevertheless a few comments are in order. Under optimum conditions a molecular flow type leak would appear to be the best type to use. With it one would be assured that the gas sampling process would be free from discrimination. Furthermore, the flow would be a linear function of pressure, certainly a desirable situation. In the interests of simplicity and weight conservation a two-stage admission system does not appear feasible. Thus the molecular leak would have to operate with a very high pressure drop. This, coupled with the low pumping speed of the vacuum system, would mean that extremely small leak holes would have to be employed--smaller than used in instruments now on the market. No doubt means could be devised to make such holes. However, extreme care would have to be taken to protect the holes against being plugged by microscopic dust particles.

Should it not appear practical to develop a satisfactory molecular leak, we believe one should not overlook the fact that a viscous leak, although it has disadvantages, can give highly satisfactory results and has been successfully used in a number of applications[3,4]. A simple leak such as described by Halsted and Nier[4] can be adjusted to fit the pressure range expected. While not so susceptible to plugging as the molecular leak, one would, as a precaution, employ two or more such leaks in parallel and carefully protect the inputs by suitable filters.

In conclusion, the following comments may be in order. We seriously question whether at this stage of development one should be too concerned about whether the flow is molecular, viscous, or something in between. The gases expected have roughly the same molecular weights, and at worst one would have a discrimination proportional to the square root of the molecular weight. Thus if one assumed CO_2 and N_2 to be the heaviest and lightest gases respectively for which one sought accurate data, the largest discrimination factor would be $(44/28)^{1/2} = 1.25$. Thus if one arbitrarily assumed a discrimination factor of 1.12, one would make an error of only 12 percent if under the sampling conditions the flow should happen to be either purely molecular or purely viscous. Certainly one

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would know the flow characteristics of any leak employed better than this. When one couples this consideration with the fact already discussed, namely the difficulty of obtaining a pump system which may not have far more serious discrimination characteristics, it does not appear profitable to pursue the leak problem too far, especially if this effort came at the expense of work on other phases of the problem which at this time appear more serious. In our case, it would seem more profitable to devote effort to the pumping problem, the development of reliable electronics, and other aspects which may determine the success or failure of the project and to return to the leak problem at a later date.

III. A PROPOSED BREADBOARD DESIGN

A. Mass Spectrometer and Pumping System

This would be a 60°, 1.5-inch instrument essentially like that described under II-A-3. The collector assembly would be replaced by a very simple lightweight unit with a shell just large enough to accommodate the collector itself. The source assembly would be retained essentially as in the test unit. To provide the differential pumping, the parts would be built on a base plate fastened to the analyzer tube. The source would be covered by a thin shell welded in place.

The magnet would be similar to that described in section II-B and shown in Fig. 13. The inner diameter of the ring from which the Alnico poles are cut would be smaller to provide a field region for a sputter pump which would be attached inside the bent analyzer tube. Hopefully an anode area at least half of that used in the test pump could be employed.

The entire vacuum housing would be mounted in a magnesium block to which would also be attached the various electronic circuits. For the overall package we visualize a rectangular parallelopiped having a shape approximating a cigar box and meeting the volume limitations given in the specifications. The various electronic units would be bolted and cemented to the same block and mounted in such a way as to minimize length of leads, etc. Except for metal needed to insure rigidity and provide shielding, excess material would be cut out of the block. Thus when complete it would resemble an empty cigar box having several partitions and bosses for fastening components.

B. Electronics

We propose circuits similar to those discussed earlier. The amplifier would be essentially like that described. However, to conveniently present signals having as large a range of intensity as expected, some compression means must be considered. One arrangement would be to attach some device which would reduce the signal to a logarithmic one or some other convenient form. In connection with another mass spectrometer problem, we have developed a successful amplifier which includes a variable attenuator. It may be that an adaptation of this would be employed in the present instance. Unfortunately there was not time to fully explore the problem.

For an emission regulator, we propose the low power one built for the design study (Fig. 15E). For scanning the spectrum we propose a circuit similar to that shown in Fig. 15D. This circuit will require additional engineering. We know, for example, that the bleeder chain has a far higher resistance than necessary. A lower resistance would reduce difficulties caused by leakage currents in the Schockley diodes.

C. Gas Inlet System

We would propose several viscous leaks, such as pinched tubes in parallel, and protected by a filter at the input end. A thin diaphragm would cover the entrance until the vehicle was out of the earth's atmosphere.

when sufficient altitude was reached, the diaphragm would be ruptured by some device such as a squib-operated knife. Thus during the flight between planets the leak could act as a very low pumping-speed pump and take care of outgassing of the system. Alternatively, one could defer breaking the diaphragm until the capsule actually entered the Martian atmosphere. This might place too much of a total load on the sputter pump and would have to be investigated further. It does not seem one can make a firm decision until one knows more about the space craft itself--the danger of contamination from steering rockets or other sources. The JPL specifications give no information on this point.

D. Power Consumption and Weight

Power consumption for the several units is estimated to be as follows:

Electrometer tube amplifier		1.0*
Emission regulator and ion acceleration power supply		2.9
Sputter pump power supply operating at 10^{-5} torr		0.3
Addition to amplifier to produce logarithmic or other modification of signal		0.1
	Total	4.3 watts

Total weight of the unit is estimated as follows:

Mass spectrometer tube with sputter pump but without main magnet		0.7	
Main magnet complete with shields		2.3	
Hollow magnesium block with internal shields and brackets for mounting all equipment		1.6	
Assume 6-sided box of magnesium, 6" x 9" x 3", wall thickness 1/16". Assume shields and brackets weigh as much as shell.			
Gas leak plus squib mechanism		0.1	
		4.7	4.7 lb.
Electronic Supplies:			
Electronic tube amplifier, including possible logarithmic modifier (amplifier = 0.2 lb., modifier = 0.2 lb. ?)	.4		
Emission regulator	.7		
Ion acceleration power supply	.4		
Sputter pump power supply	.3		
Base drive power supply and input converter	.4		
Epoxy resin for assembly	.2		
Mounting terminals	.1		
	2.5		2.5 lb.
Total Weight			7.2 lb.

*This figure can be cut to 0.5 watts at the expense of some complications.

IV. SUMMARY AND DISCUSSION

On the basis of the present study, as well as previous experience, it appears quite practical to design and construct a magnetic deflection mass spectrometer which will either meet or come close to meeting the specifications set down in the work statement. There remain a number of problems, the solution of which will determine the ultimate success or failure of the project.

The most serious of these is probably the reliability of the electronics associated with the mass spectrometer. Particularly vulnerable are the electrometer tubes used in the ion current measuring system. In general, electronic apparatus is less likely to fail if it is left turned on. However, the chance of failure of an electrometer tube during the long journey to Mars is so great that it would probably be best to leave the amplifier turned off until actual analyses are to be started.

If a reliable solid state substitute for the CK5889 tubes became available, this obviously would materially increase the chances of success. Alternatively, if an electron multiplier existed which met the weight specifications and could be relied on to maintain a sufficiently high gain so that one could count individual ions, we obviously would have a very happy situation both from the standpoint of sensitivity and from the ease of processing the data. Electrometer tubes could then be omitted entirely. Even if one could not have an electron multiplier with sufficient gain to permit the counting of individual ions, a low gain multiplier with a stable gain might still be used as a substitute for an electrometer tube. It is doubtful, however, if one could be sure that the gain would not change during the 6-month trip. The problem is further complicated by th fact that the sensitivity of the input stage depends upon the type of ion which impinges. The calibration would probably change with time.

In the limited time available for the design study there was no opportunity to check the reliability of the circuits at different temperatures or if they are subject to temperature cycles. Clearly such studies are imperative before any final design or instrument is adopted.

In the present study, it was not possible to find time to develop an amplifier which would compress the signal to give, for example, a logarithmic response, and which would meet any reasonable specifications for reliability. This, too, requires further study.

A possible answer to the electronic reliability question would be to actually have a duplicate set of electronic circuits which would be switched into place automatically if the spectrometer did not give an output signal at the time one was expected. If one were to consider duplication it might suffice to have a duplicate ion measuring circuit only since this is certainly the most vulnerable part of the circuitry.

The 3 mil tungsten wire spectrometer source filament should be adequate for the job. A similar filament has been employed in mass spectrometers developed for upper atmosphere investigations and no difficulty has been encountered with burn-out. The relatively low power consumption as compared with that for a heavier filament is an attractive feature. While one might go to an even lighter filament and hence cut the power even further, we are not prepared to recommend such a step at this time. The risk of burn-out may be too great. Since experience along this line is limited, tests are in order.

In the present study, attention was finally focused on a ou-, would not change weight by more than a negligible amount.

In the discussion in section II-D no account was taken of the improvement in resolution resulting from reducing the slit in G_1 for the purpose of giving a more predictable pumping speed. While there will be some improvement in resolution, it surely will not be a linear effect, since we are approaching the point where aberrations due to a variety of causes are playing a more significant part in determining the ultimate resolution. It is to be noted that the reduction in sensitivity resulting from a reduction in slit sizes will not be a problem other than putting a more serious strain on the ion current detector. In a certain sense the present instrument is "over designed" so far as sensitivity and resolution are concerned, and a reduction in size and weight seems quite feasible. Moreover should further consideration of the discrimination problem, resulting from non-predictable pumping speed and sampling, lead to a relaxation of the specification on accuracy of analysis, there is no doubt whatsoever but that an additional reduction in weight could be accomplished.

In conclusion, the present study shows that a magnetic deflection instrument appears practical for the investigation of planetary atmospheres. Rather than dissipate time at present in attempting to reduce the weight through a reduction in size as mentioned as a possibility above, we would urge that as a next step in the investigation, a breadboard model be constructed. This would <u>make</u> <u>possible</u> <u>actual</u> <u>studies</u> of reliability, accuracy, sensitivity and other factors of prime interest. From such a study one would also have a much better evaluation of the actual weight of a practical instrument. The additional knowledge gained on all aspects of the problem would enable one to predict much more accurately the effect of changes in design which may appear desirable.

RE-ORDER No. 62-542

Special thanks are due R. L. Howard and S. W. Nelson who were responsible for the electronic designs, R. B. Thorness who designed and supervised most of the mechanical construction, and D. G. Seal who carried out most of the experimental work.

V. REFERENCES

1. A. O. Nier, Rev. Sci. Instr. 31, 1127 (1960).

2. R. B. Thorness and A. O. Nier, Rev. Sci. Instr. 33, 1116 (1962).

3. A. O. Nier et al, Anal. Chem. 20, 188 (1948).

4. R. E. Halsted and A. O. Nier, Rev. Sci. Instr. 21, 1019 (1950).

RE-ORDER No. 62-542

Figure 1

Schematic drawing of 90°, two inch radius of curvature mass spectrometer showing ion source and collector assemblies. Filament is of 0.003" tungsten wire in shape of hairpin. Slits in S, G_1, G_2 and G_3 have dimensions 0.080" x 0.312", 0.010" x 0.4", 0.020" x 0.4, 0.040" x 0.25", respectively. Split focusing plates J_1 and J_2 are separated by 0.040". Separation between R and S is 0.140", between S and J_1, J_2, 0.080", between J_1, J_2 and G_1, 0.140" and between G_1 and G_2, 0.300". As is customary in instruments of this style, plate E ahead of collector is maintained at a negative potential and supresses secondary electrons emitted either from edges of slit in G_3 or from collector C due to ion bombardment. A pair of small bar magnets mounted on sides of electron beam (not shown in figure) collimate the electron beam. The strength of the field in the region of the electron beam is approximately 500 gauss and influences the specific sensitivity of the source. The variation in sensitivity between tests is due primarily to the fact that the field was not always the same.

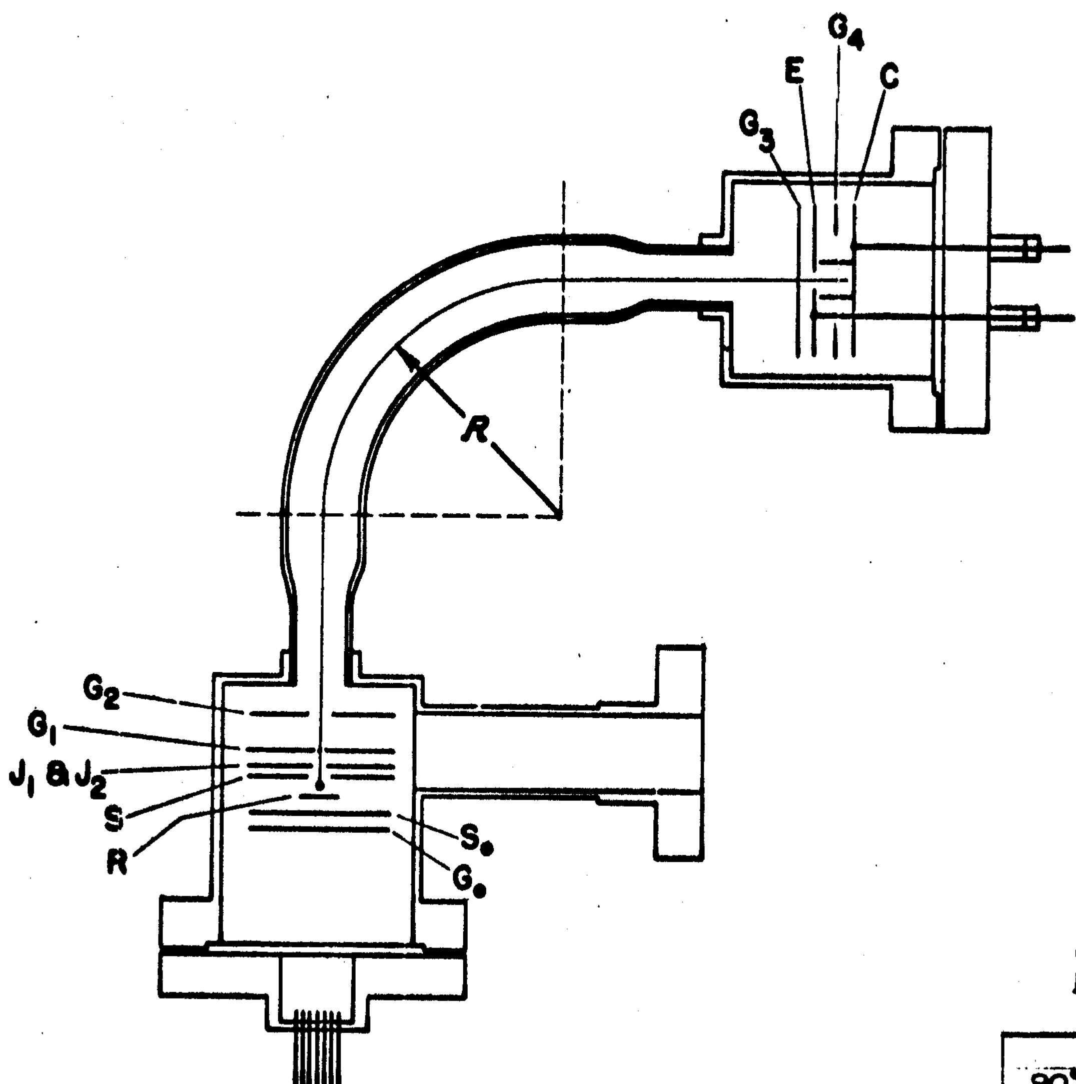

FIG. 1

SCHEMATIC
90°, 2"R MAGNETIC SPECTROMETER

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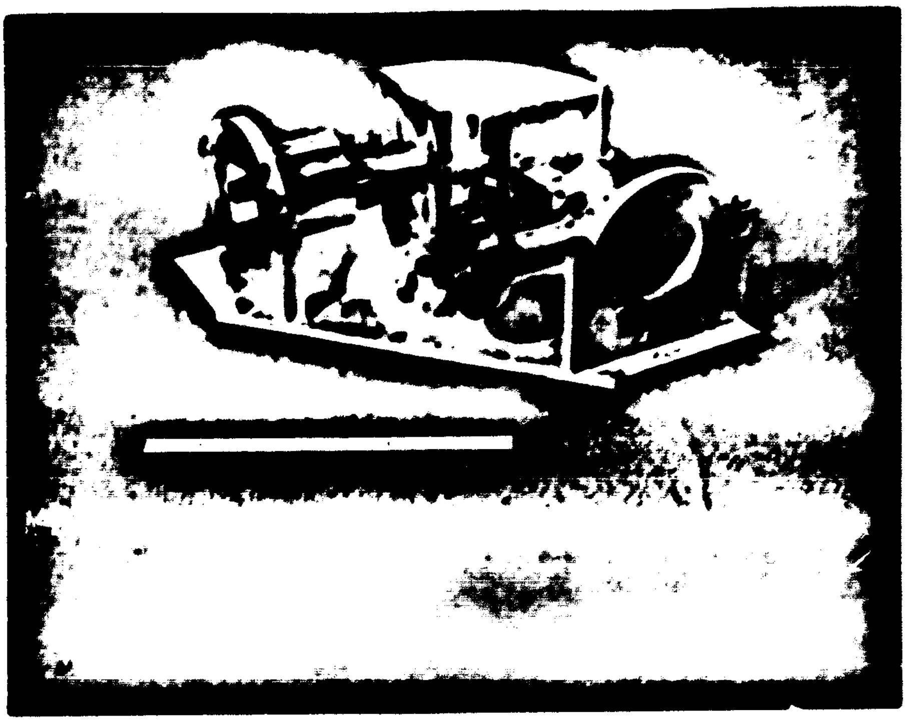


Fig. 2. 90°, 2-inch-radius spectrometer tube complete with magnet but without ion source and collector assemblies. Magnetic shields at ends of magnet have been removed to make magnet poles visible. 6-inch rule indicates approximate size.

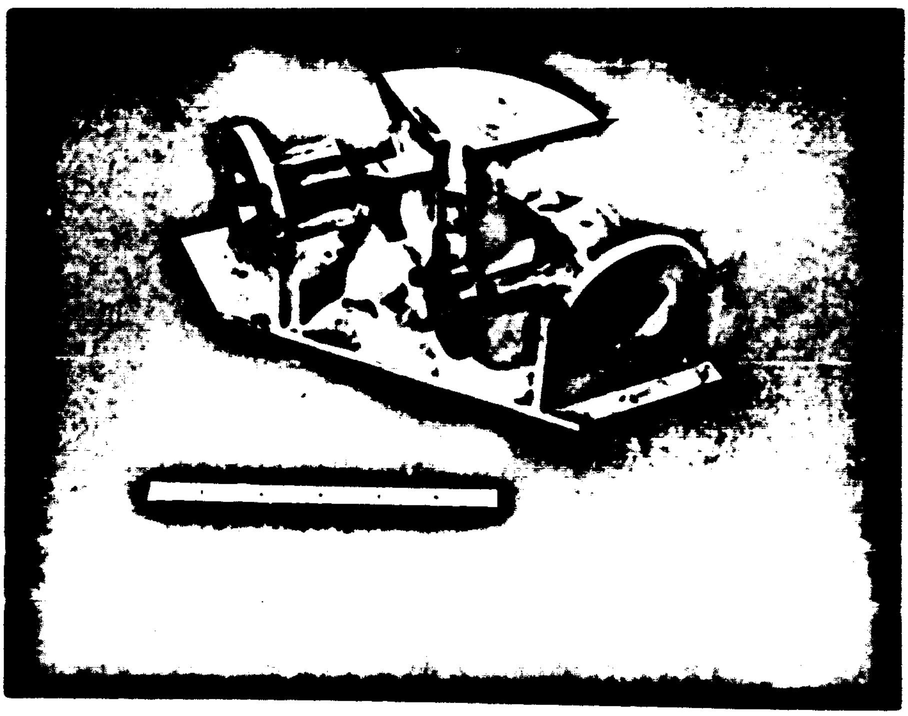


Fig. 3. Same picture as Fig. 2 except magnetic shields cover open parts of magnet yoke.

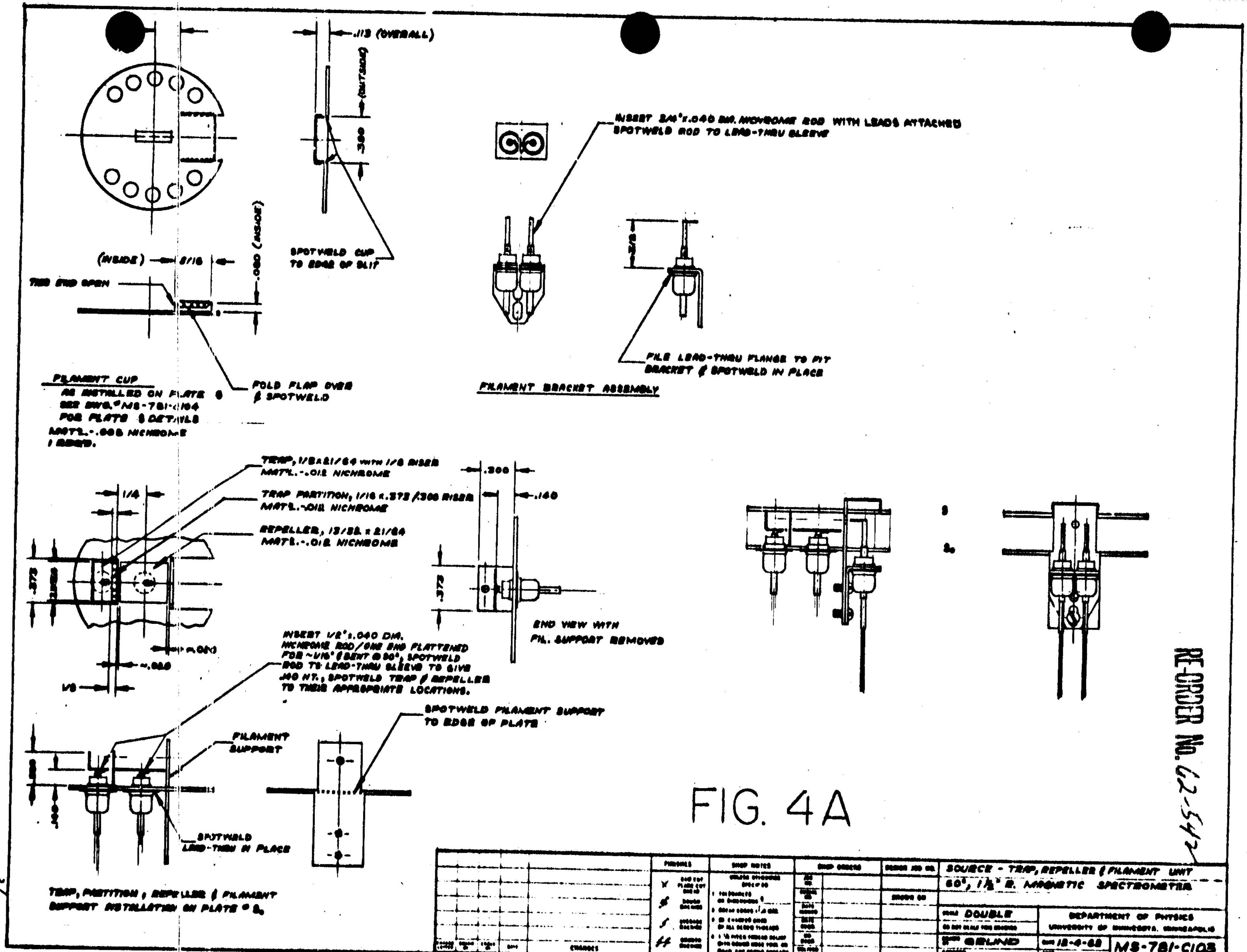
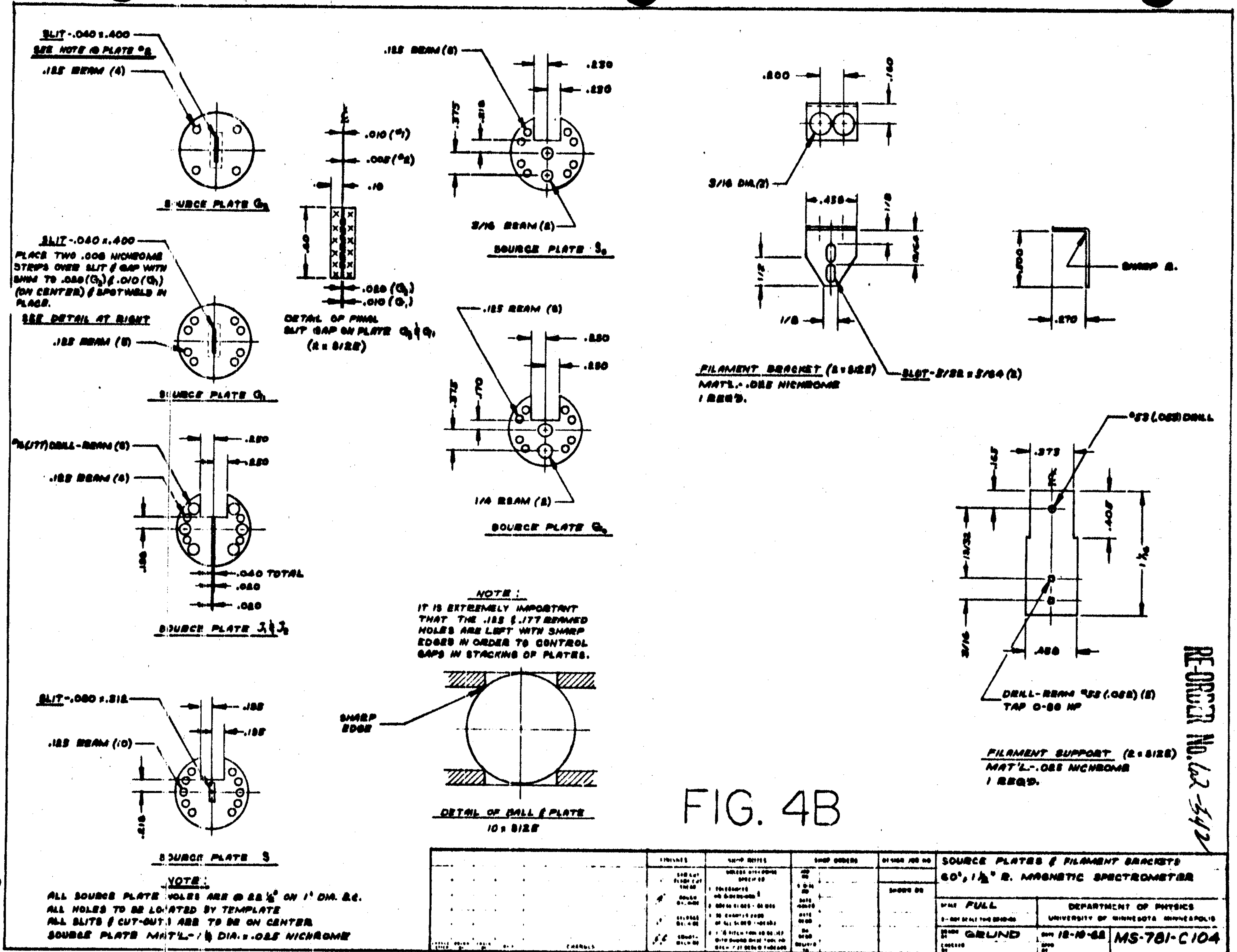

.113 (OVERALL)
(OUTSIDE)
.380
SPOTWELD CUP TO EDGE OF SLIT
(INSIDE)
5/16
.080 (INSIDE)
THIS END OPEN
FOLD FLAP OVER & SPOTWELD
FILAMENT CUP
AS INSTALLED ON PLATE 8
SEE DWG. # MS-781-C104
FOR PLATE 8 DETAILS
MAT'L.-.005 NICHROME
1 REQ'D.
INSERT 3/4" x .040 DIA. NICHROME ROD WITH LEADS ATTACHED
SPOTWELD ROD TO LEAD-THRU SLEEVE
3/8
FILE LEAD-THRU FLANGE TO FIT
BRACKET & SPOTWELD IN PLACE
FILAMENT BRACKET ASSEMBLY
TRAP, 1/8 x 21/64 WITH 1/8 RISER
MAT'L.-.012 NICHROME
TRAP PARTITION, 1/16 x .373 /.300 RISER
MAT'L.-.012 NICHROME
REPELLER, 13/32 x 21/64
MAT'L.-.012 NICHROME
1/4
.373
.300
.140
1/8
END VIEW WITH
FIL. SUPPORT REMOVED
INSERT 1/2" x .040 DIA.
NICHROME ROD/ONE END FLATTENED
FOR ~1/16" & BENT @ 90°, SPOTWELD
ROD TO LEAD-THRU SLEEVE TO GIVE
.160 HT., SPOTWELD TRAP & REPELLER
TO THEIR APPROPRIATE LOCATIONS.
SPOTWELD FILAMENT SUPPORT
TO EDGE OF PLATE
FILAMENT SUPPORT
SPOTWELD
LEAD-THRU IN PLACE
TRAP, PARTITION, REPELLER & FILAMENT
SUPPORT INSTALLATION ON PLATE # 8
RE-ORDER No. 62-542
SOURCE - TRAP, REPELLER & FILAMENT UNIT
60°, 1½" R. MAGNETIC SPECTROMETER
DOUBLE
DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA, MINNEAPOLIS
12-4-68
MS-781-C103
CHANGES

FIG. 4A



SLIT-.040 x .400
SEE NOTE @ PLATE G2
.125 REAM (4)
SOURCE PLATE G2
SLIT-.040 x .400
PLACE TWO .005 NICHROME STRIPS OVER SLIT & GAP WITH SHIM TO .020(G2) & .010(G1) (ON CENTER) & SPOTWELD IN PLACE.
SEE DETAIL AT RIGHT
.125 REAM (8)
SOURCE PLATE G1
DETAIL OF FINAL SLIT GAP ON PLATE G2 & G1 (2 x SIZE)
.125 REAM (8)
3/16 REAM (2)
SOURCE PLATE S0
.125 REAM (8)
1/4 REAM (2)
SOURCE PLATE G0
.177 DRILL-REAM (8)
.125 REAM (4)
.040 TOTAL
SOURCE PLATE S1 & S2
SLIT-.080 x .312
.125 REAM (10)
SOURCE PLATE S
NOTE:
ALL SOURCE PLATE HOLES ARE @ 22 1/2° ON 1" DIA. B.C.
ALL HOLES TO BE LOCATED BY TEMPLATE
ALL SLITS & CUT-OUTS ARE TO BE ON CENTER
SOURCE PLATE MAT'L-1 1/8 DIA. x .025 NICHROME
NOTE:
IT IS EXTREMELY IMPORTANT THAT THE .125 & .177 REAMED HOLES ARE LEFT WITH SHARP EDGES IN ORDER TO CONTROL GAPS IN STACKING OF PLATES.
SHARP EDGE
DETAIL OF BALL & PLATE
10 x SIZE
3/16 DIA.(2)
SLOT-3/32 x 3/64 (2)
FILAMENT BRACKET (2 x SIZE)
MAT'L.-.025 NICHROME
1 REQ'D.
SHARP R.
#53 (.059) DRILL
DRILL-REAM #53 (.059) (2)
TAP 0-80 NF
FILAMENT SUPPORT (2 x SIZE)
MAT'L.-.025 NICHROME
1 REQ'D.
SOURCE PLATES & FILAMENT BRACKETS
60°, 1 1/2" R. MAGNETIC SPECTROMETER
FULL
DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA MINNEAPOLIS
GRUND
12-19-62
MS-781-C104
RE-ORDER No. 62-342

FIG. 4B

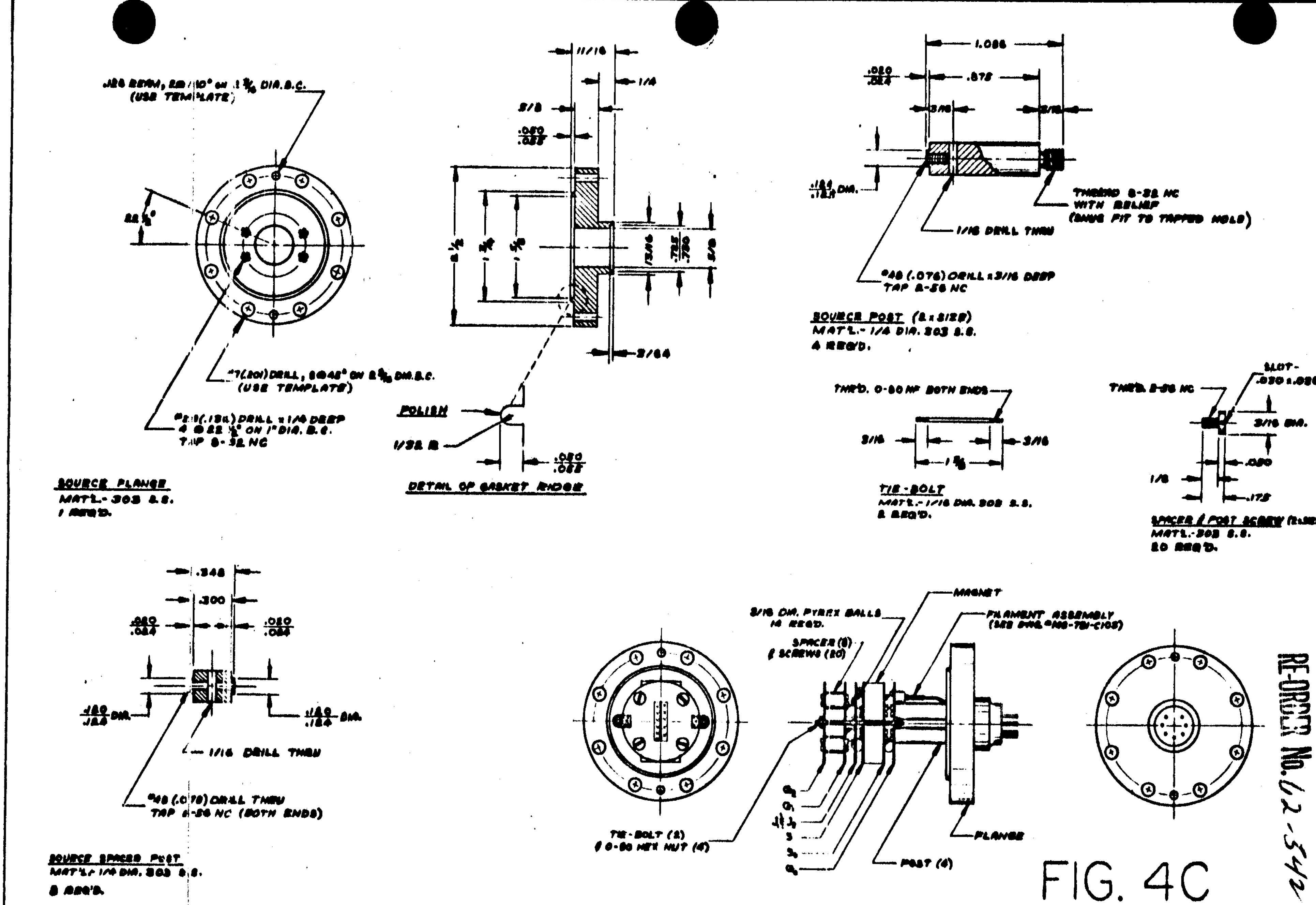


FIG. 4C

SOURCE GENERAL ASSEMBLY & MISC. PARTS
60°, 12" R. MAGNETIC SPECTROMETER

SCALE FULL

DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA, MINNEAPOLIS

DRAWN GBLAND — DATE 12-1-62

MS-78I-C105

RE-ORDER No. 62-542

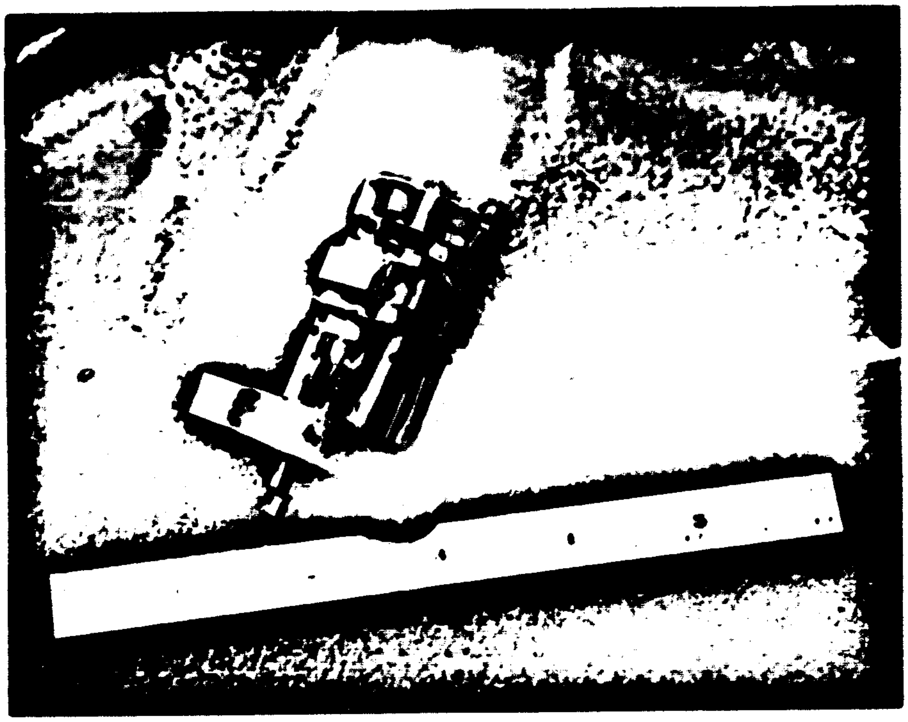
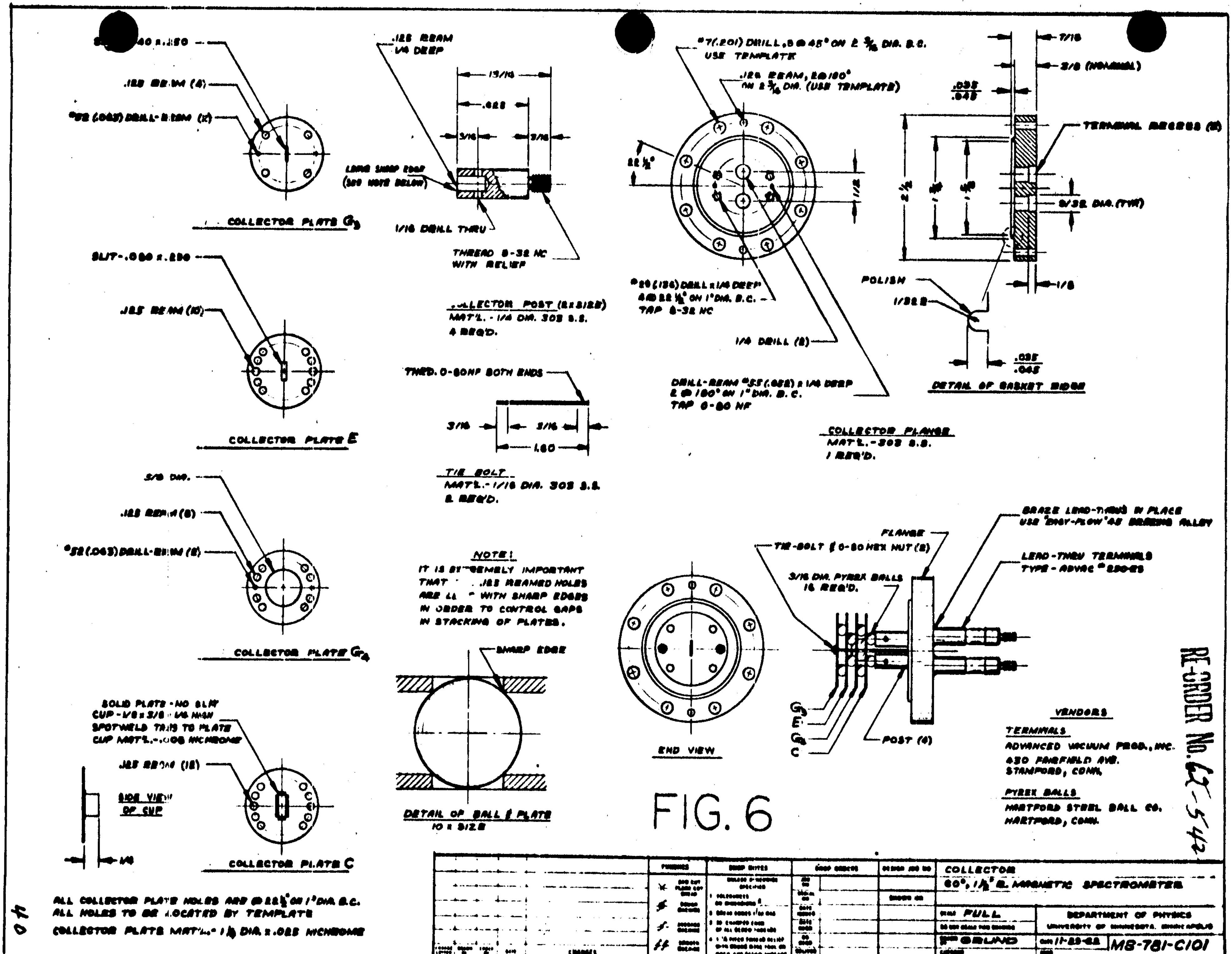


Fig. 5. Ion source assembly. 6-inch ruler indicates approximate size.


.125 REAM (4)
COLLECTOR PLATE G_3
SLIT-.030 x .250
.125 REAM (10)
COLLECTOR PLATE E
3/8 DIA.
.125 REAM (8)
COLLECTOR PLATE G_2
SOLID PLATE - NO SLIT
.125 REAM (12)
SIDE VIEW OF CUP
1/4
COLLECTOR PLATE C
ALL COLLECTOR PLATE HOLES ARE @ 22½° ON 1" DIA B.C.
ALL HOLES TO BE LOCATED BY TEMPLATE
.125 REAM
1/4 DEEP
13/16
.625
3/16
1/16 DRILL THRU
THREAD 8-32 NC
WITH RELIEF
MAT'L. - 1/4 DIA. 303 S.S.
4 REQ'D.
THRD. 0-80NF BOTH ENDS
3/16
1.60
TIE BOLT
MAT'L. - 1/16 DIA. 303 S.S.
8 REQ'D.
NOTE:
IN STACKING OF PLATES.
SHARP EDGE
DETAIL OF BALL & PLATE
10 x SIZE
#7(.201) DRILL, 8 @ 45° ON 2 3/16 DIA. B.C.
USE TEMPLATE
.124 REAM, 2 @ 180°
ON 2 3/16 DIA. (USE TEMPLATE)
22 1/2°
1 1/2
1/4 DRILL (2)
DRILL-REAM #55 (.052) x 1/4 DEEP
2 @ 180° ON 1" DIA. B.C.
TAP 0-80 NF
COLLECTOR FLANGE
MAT'L. - 303 S.S.
1 REQ'D.
END VIEW
7/16
3/8 (NOMINAL)
.035
.045
2 3/4
TERMINAL RECESS (2)
9/32 DIA. (TYP)
POLISH
1/32 R
1/8
DETAIL OF GASKET RIDGE
FLANGE
TIE-BOLT & 0-80 HEX NUT (8)
3/16 DIA. PYREX BALLS
16 REQ'D.
G_3
E
G_2
C
POST (4)
LEAD-THRU TERMINALS
VENDORS
TERMINALS
ADVANCED VACUUM PROD., INC.
430 FAIRFIELD AVE.
STAMFORD, CONN.
PYREX BALLS
HARTFORD STEEL BALL CO.
HARTFORD, CONN.
RE-ORDER No. 62-542
COLLECTOR
60°, 1/2" R. MAGNETIC SPECTROMETER
FULL
DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA, MINNEAPOLIS
11-25-62
MS-781-C101
FIG. 6

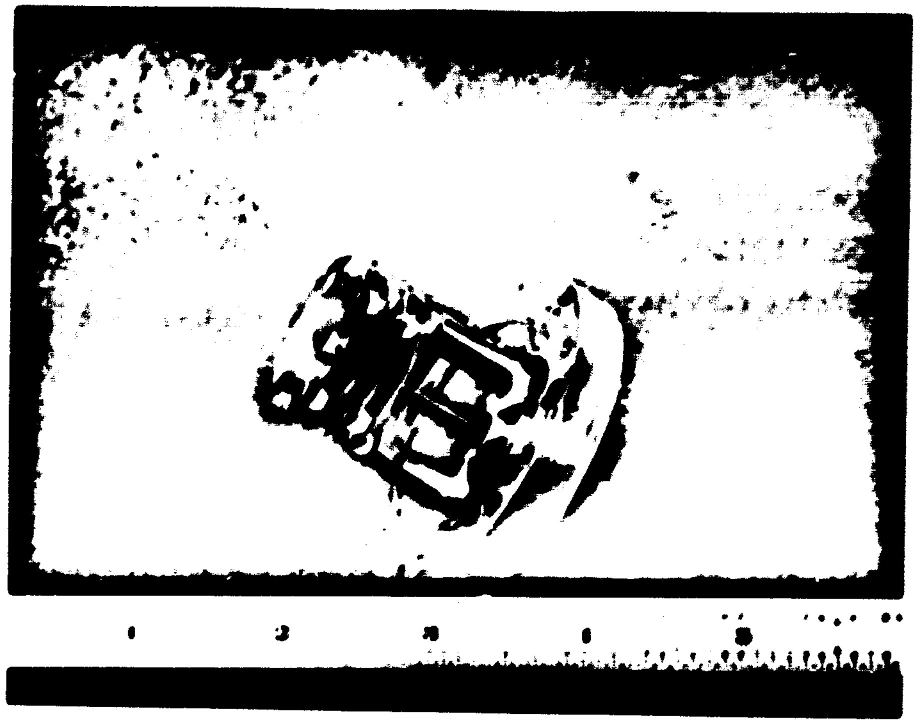


Fig. 7. Ion collector assembly. 6-inch ruler indicates approximate size.

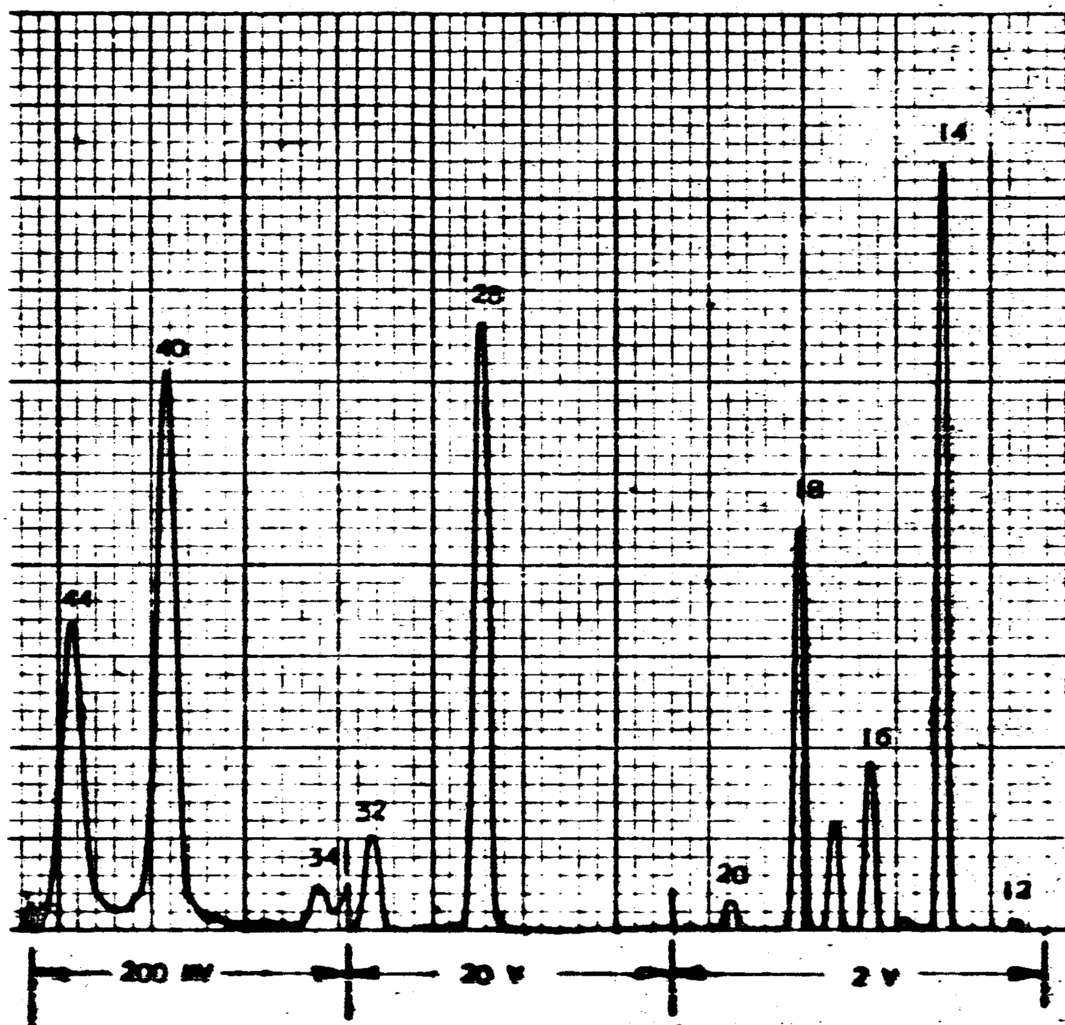


Fig. 8. Spectrum of air taken with 90°, 2-inch-radius instrument. Pressure in ion source 5×10^{-6} torr. Electron trap current 400 μa. Amplifier input resistor 10^{10} ohms. Amplifier output is attenuated to give full scale deflections as noted under chart. Thus the 28 peak gives a deflection of 13.2 volts, corresponding to an ion current of $13.2/10^{10} = 1.32 \times 10^{-9}$ amperes.

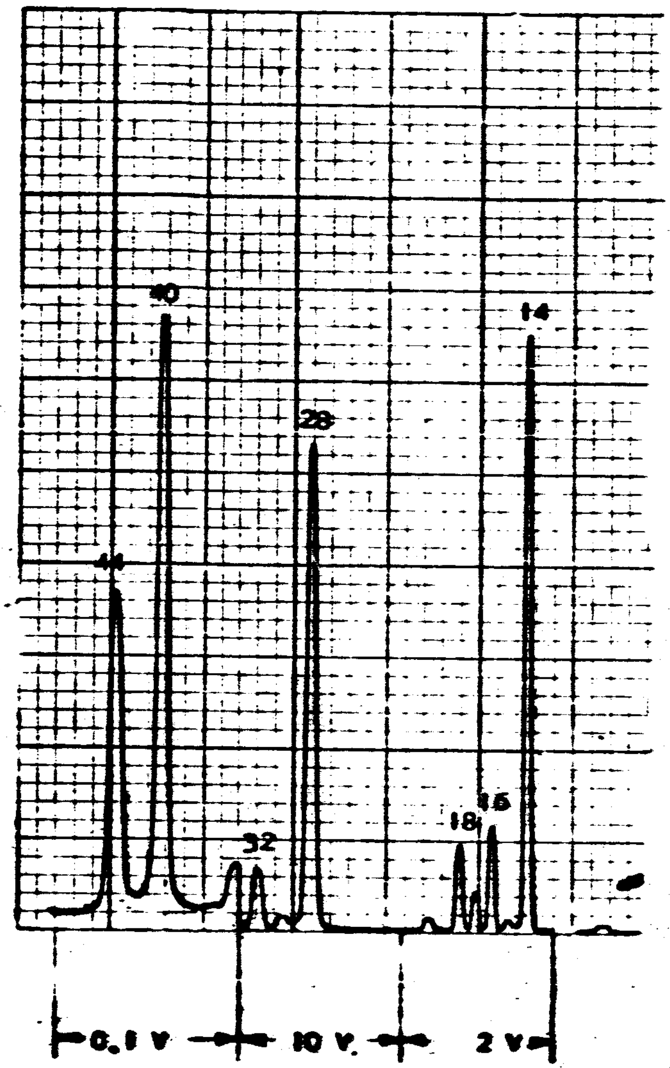


Fig. 9. Mass spectrum of air taken with 90°, 1.5-inch-radius instrument. Pressure in ion source 5×10^{-6} torr. Electron trap current 400 μa. Amplifier input resistor 10^{10} ohms. Amplifier output is attenuated to give full scale deflections as noted under chart. Thus 28 peak gives a deflection of 7.3 volts, corresponding to an ion current of $7.3/10^{10} = 7.3 \times 10^{-10}$ amperes.

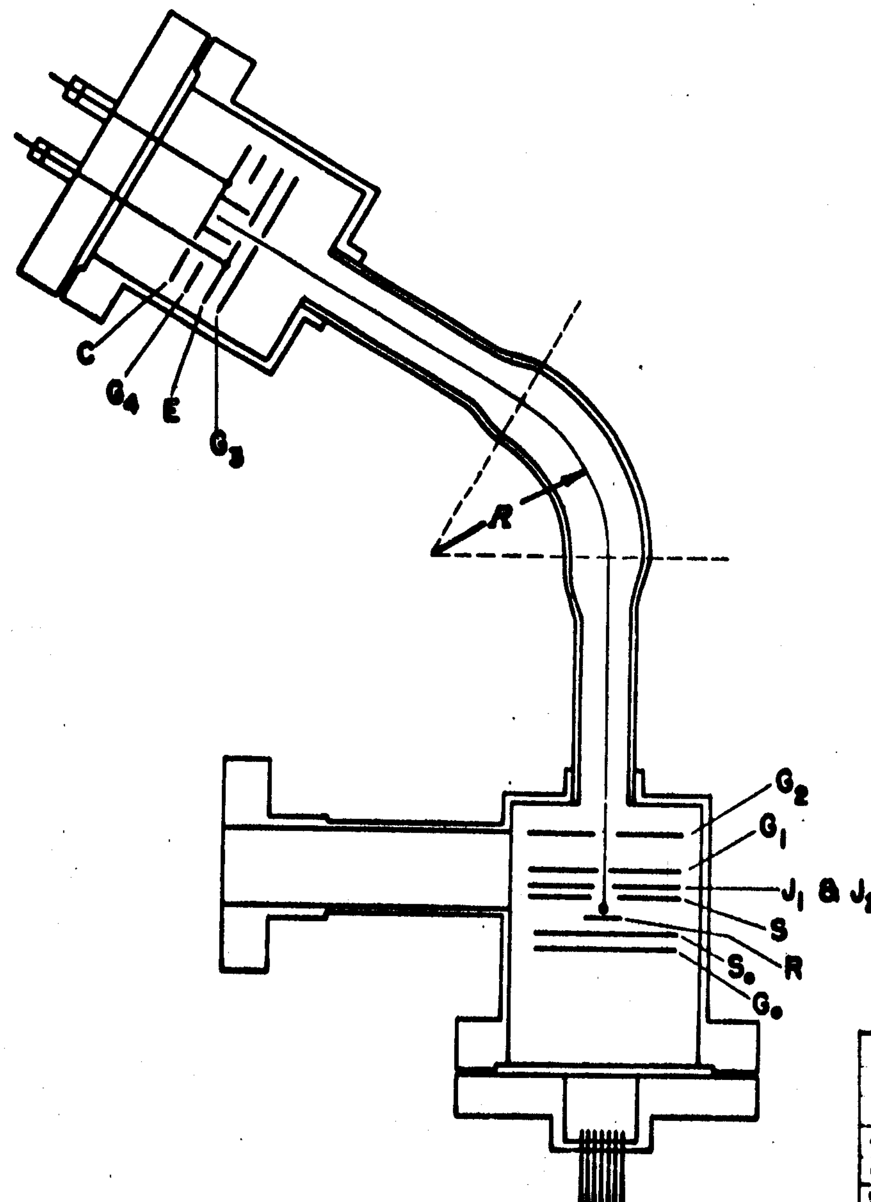


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FIG. 10

SCHEMATIC
60°, 1½" R MAGNETIC SPECTROMETER

SCALE	DEPARTMENT OF PHYSICS
DO NOT SCALE THIS DRAWING	UNIVERSITY OF MINNESOTA MINNEAPOLIS
DRAWN BY	DATE
CHECKED BY	APPD BY

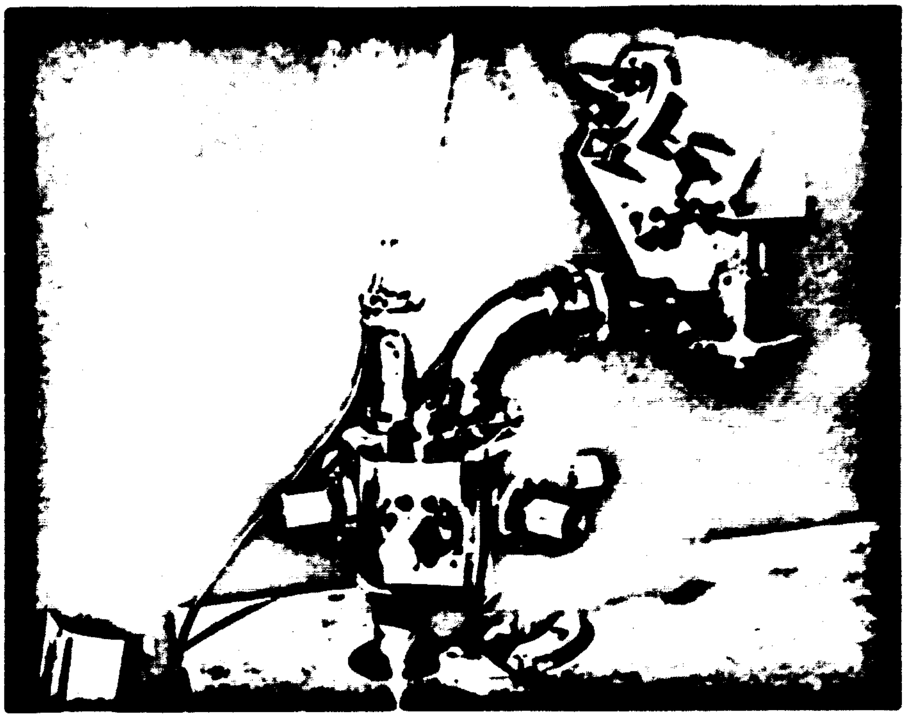


Fig. 11. Mass spectrometer tube complete with deflecting magnet, but without amplifier or connections to electronic units providing power to ion source. The instrument is bolted to valve block in lower left quarter of picture. The small sputter pump described later and shown in Figs. 15 and 16 is shown mounted on top of the valve block.

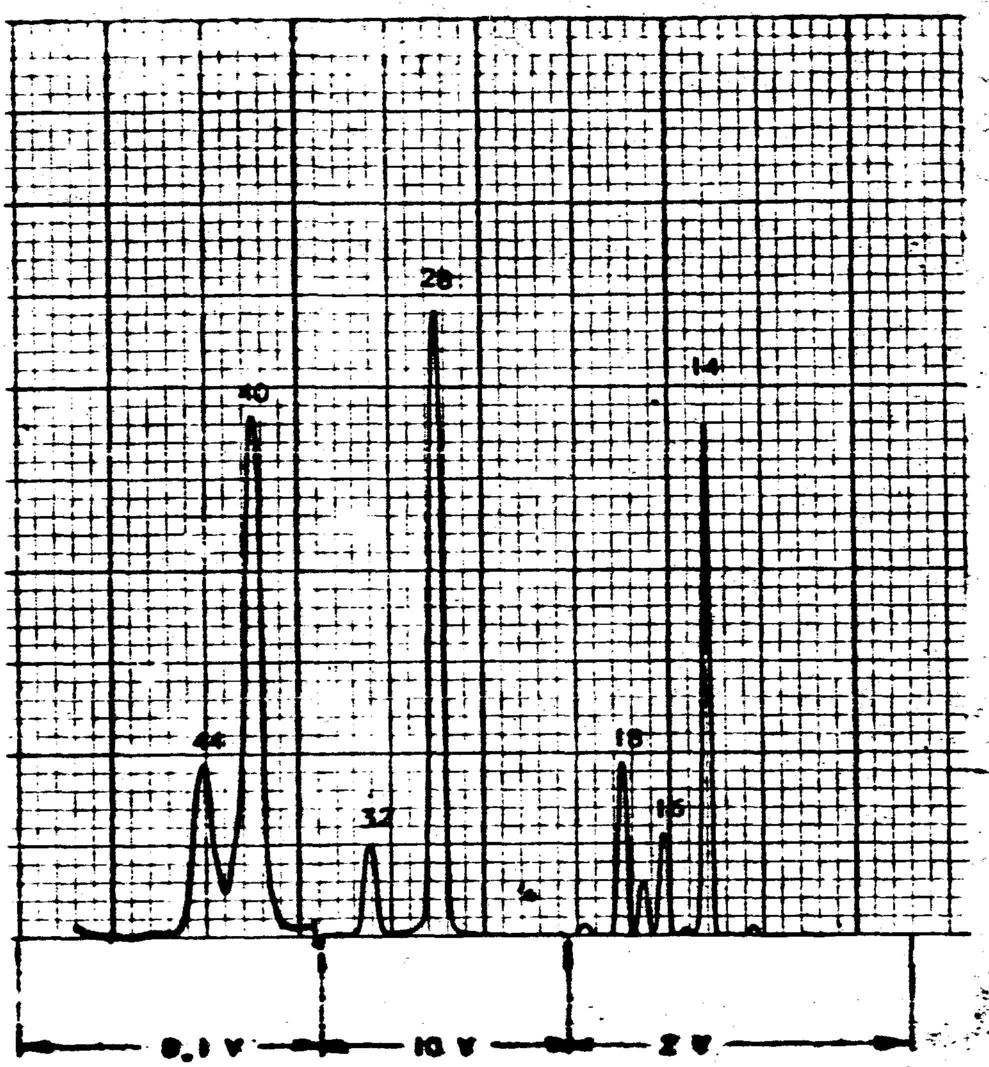
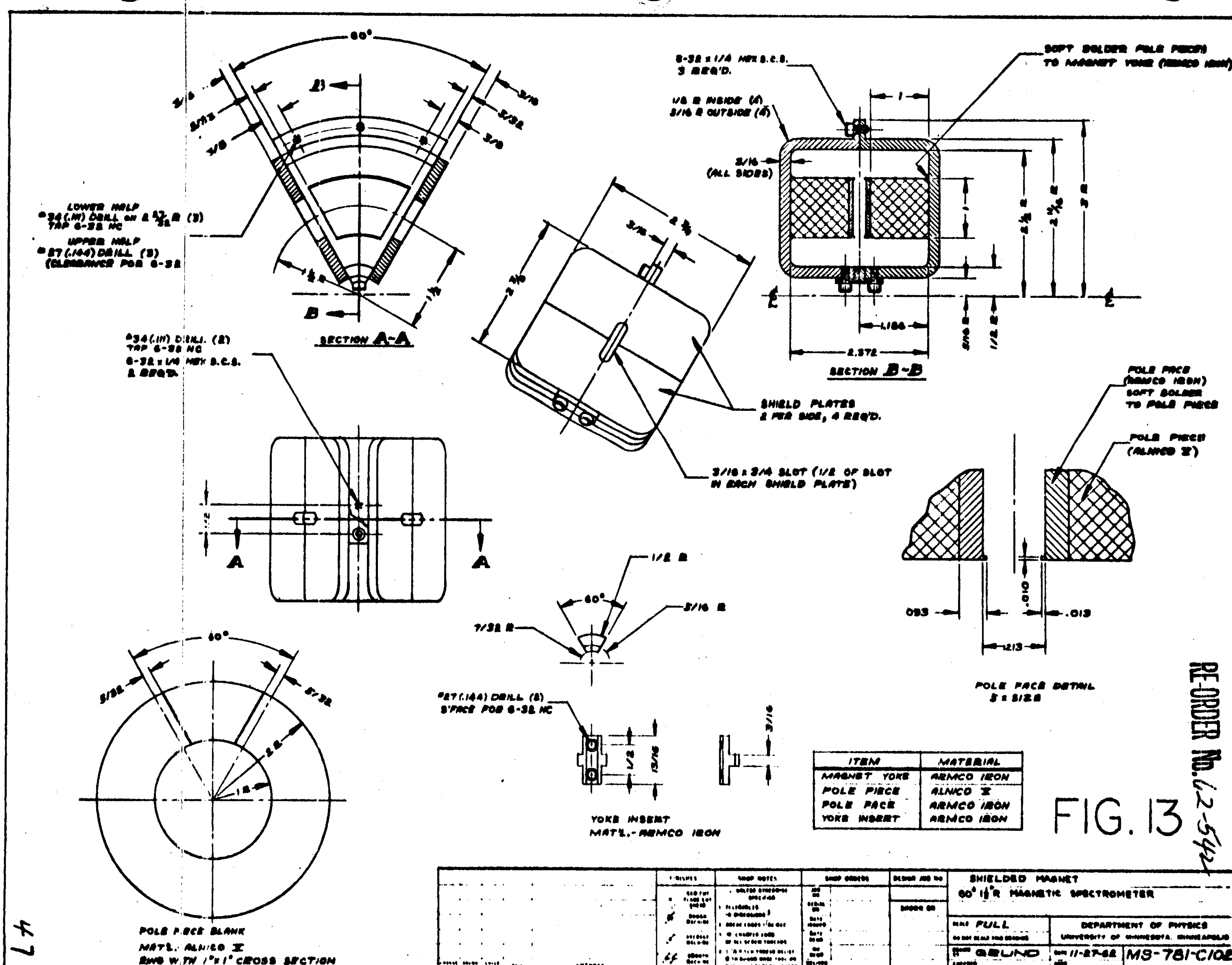


Fig. 12. Mass spectrum of air taken with 60°, 1.5-inch-radius instrument. Pressure in ion source, 5×10^{-6} torr. Electron trap current 400 μa. Amplifier input resistor 10^{10} ohms. Amplifier output is attenuated to give full scale deflections as noted under chart. Thus 28 peak gives a deflection of 6.8 volts, corresponding to an ion current of $6.8/10^{10} = 6.8 \times 10^{-10}$ amperes.



ITEM	MATERIAL
MAGNET YOKE	ARMCO IRON
POLE PIECE	ALNICO V
POLE FACE	ARMCO IRON
YOKE INSERT	ARMCO IRON

FIG. 13

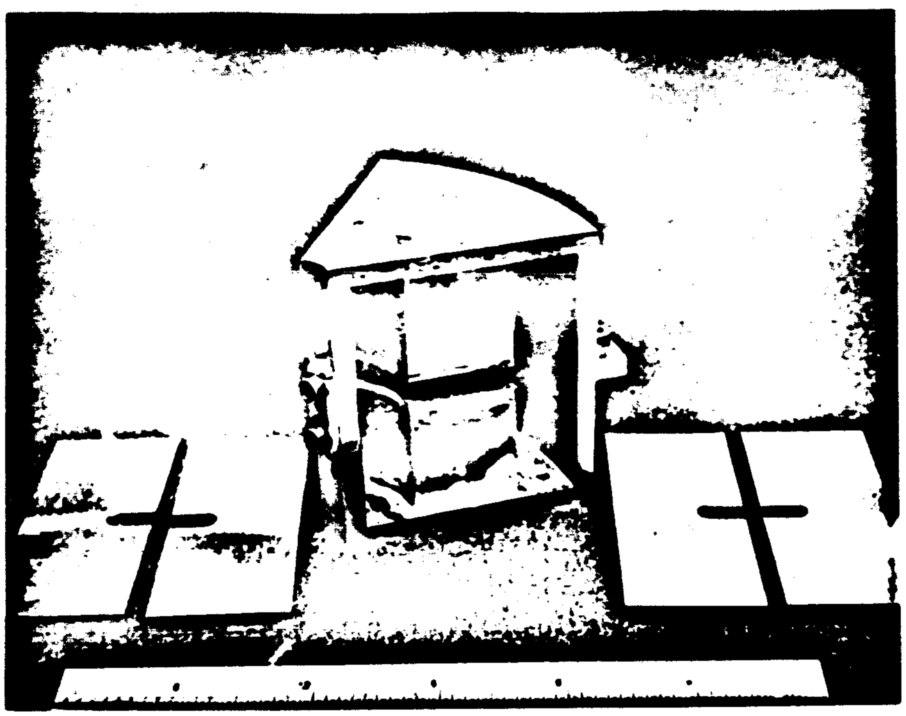


Fig. 14. Magnet employed in 60°, 1.5-inch instrument. The pole sides of the yoke which completely enclose the magnetic region are shown removed. These shields are very effective in reducing the stray field of the magnet.

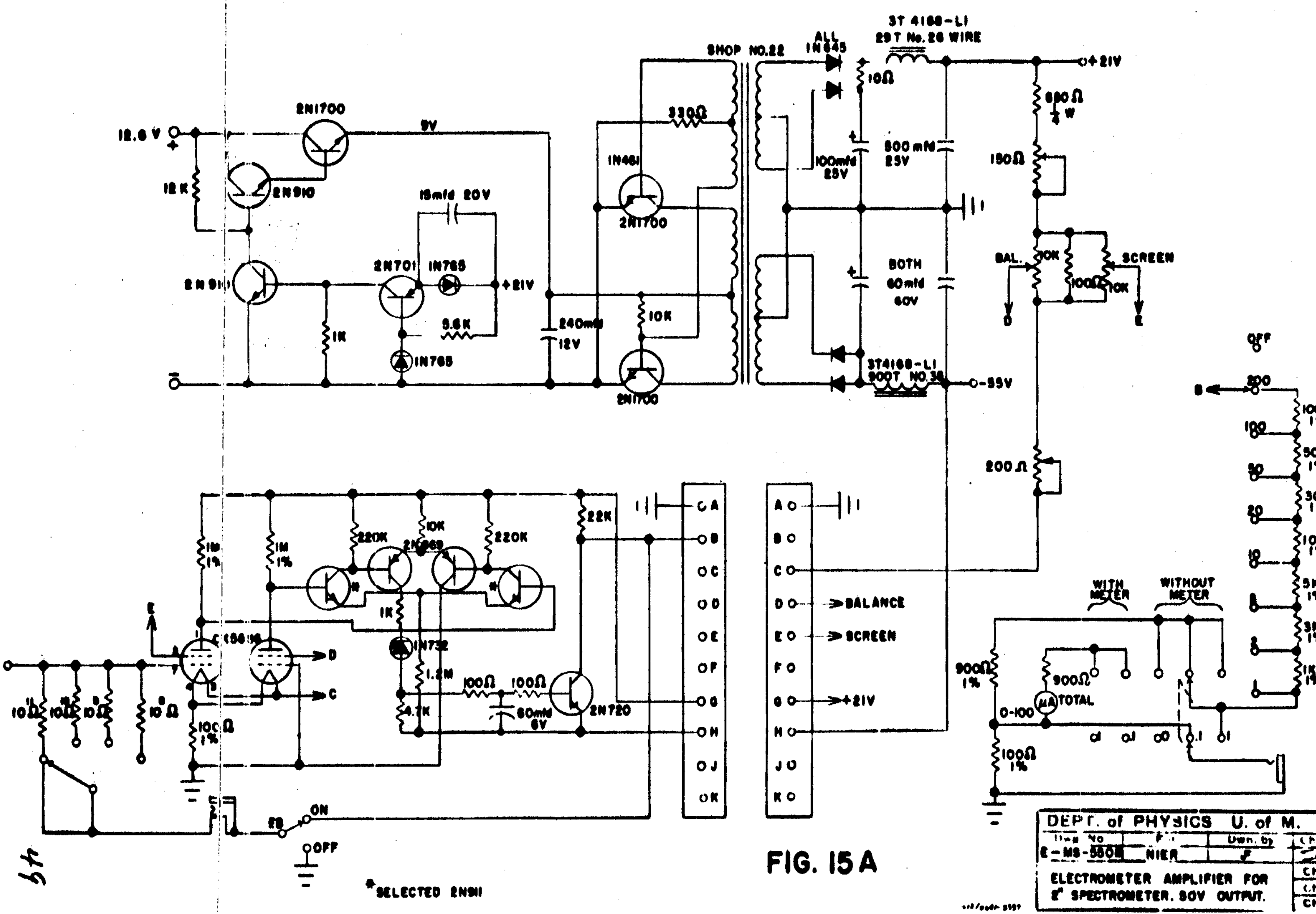


FIG. 15A

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DEPT. of PHYSICS	U. of M.	Electronic Shop		
Dwg No		Dwn. by	Checked by	Date
E-MS-5508	NIER	F	[illegible]	8-21-61
ELECTROMETER AMPLIFIER FOR 2" SPECTROMETER. 80V OUTPUT.			Change 1	
			Change 2	
			Change 3	

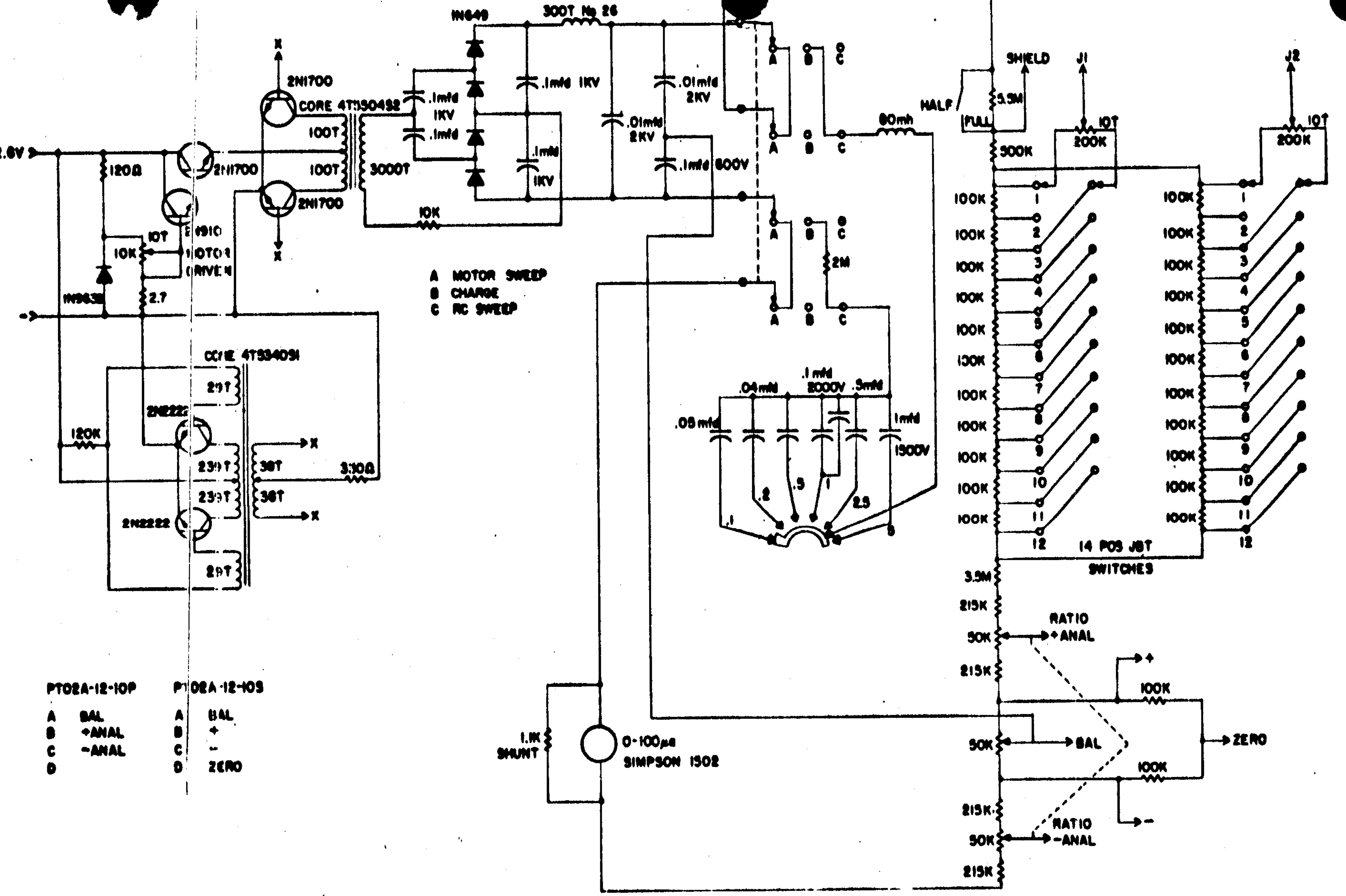

FIG. 15B

RE-ORDER No. 62-542

SCHOOL of PHYSICS UNIVERSITY of MINNESOTA				
ELECTRONICS SHOP				
ACCELERATOR & ANALYZER POWER SUPPLY FOR PLANETARY M.S.				
DRAWING NUMBER	DRN BY	FOR	CHECKED BY	DATE
E-MS-949 A	JTH	NIER	[illegible]	10-3-62
949-0841-5558-2				

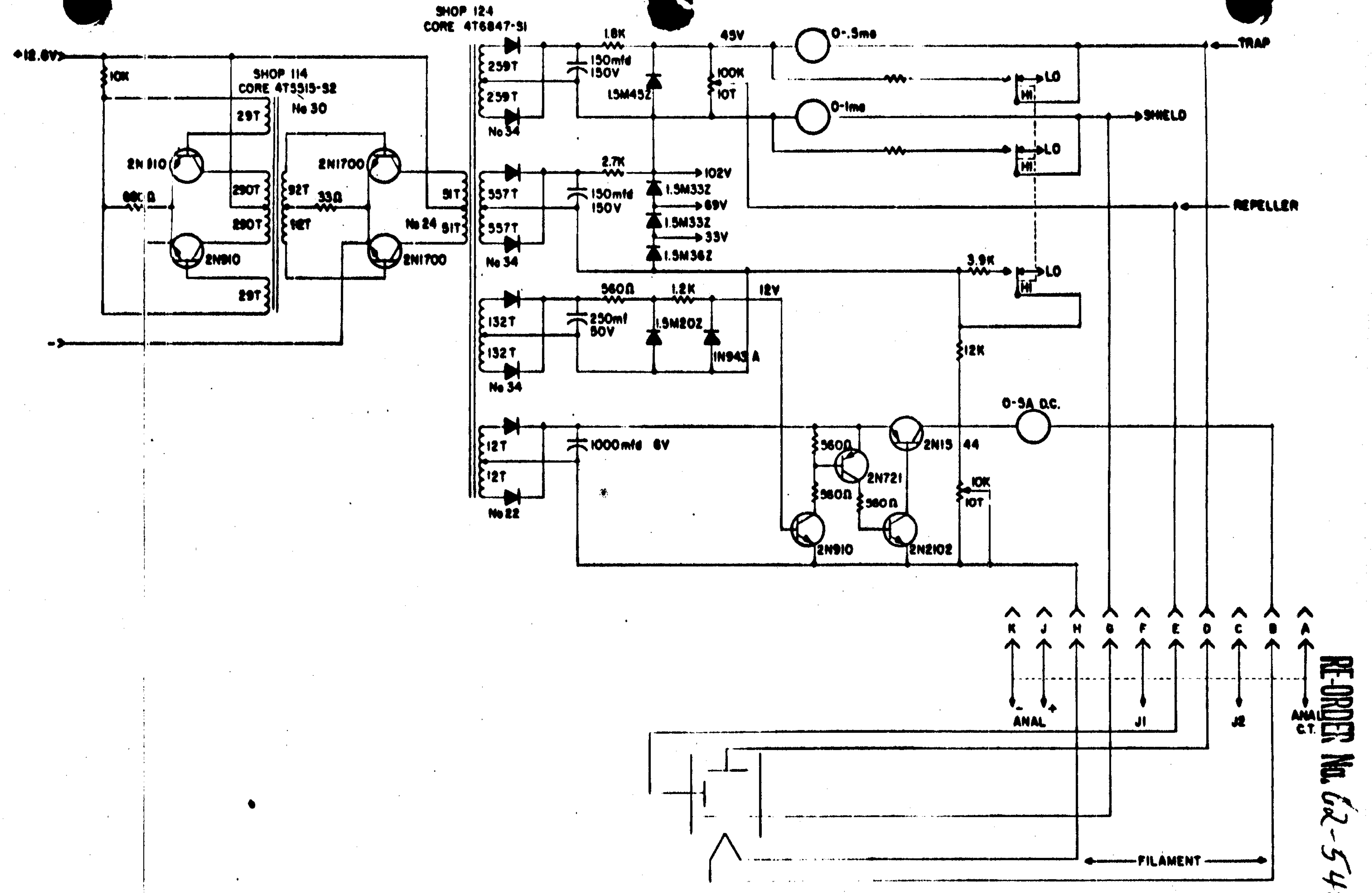

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FIG. 15 C

SCHOOL of PHYSICS UNIVERSITY of MINNESOTA

ELECTRONICS SHOP

EMISSION REGULATOR FOR PLANETARY M.S.

DRAWING NUMBER	DRN BY	FOR	CHECKED BY	DATE
E-MS-949 B	JTH	NIER	[illegible]	10-3-62
949-0641-5558-2				

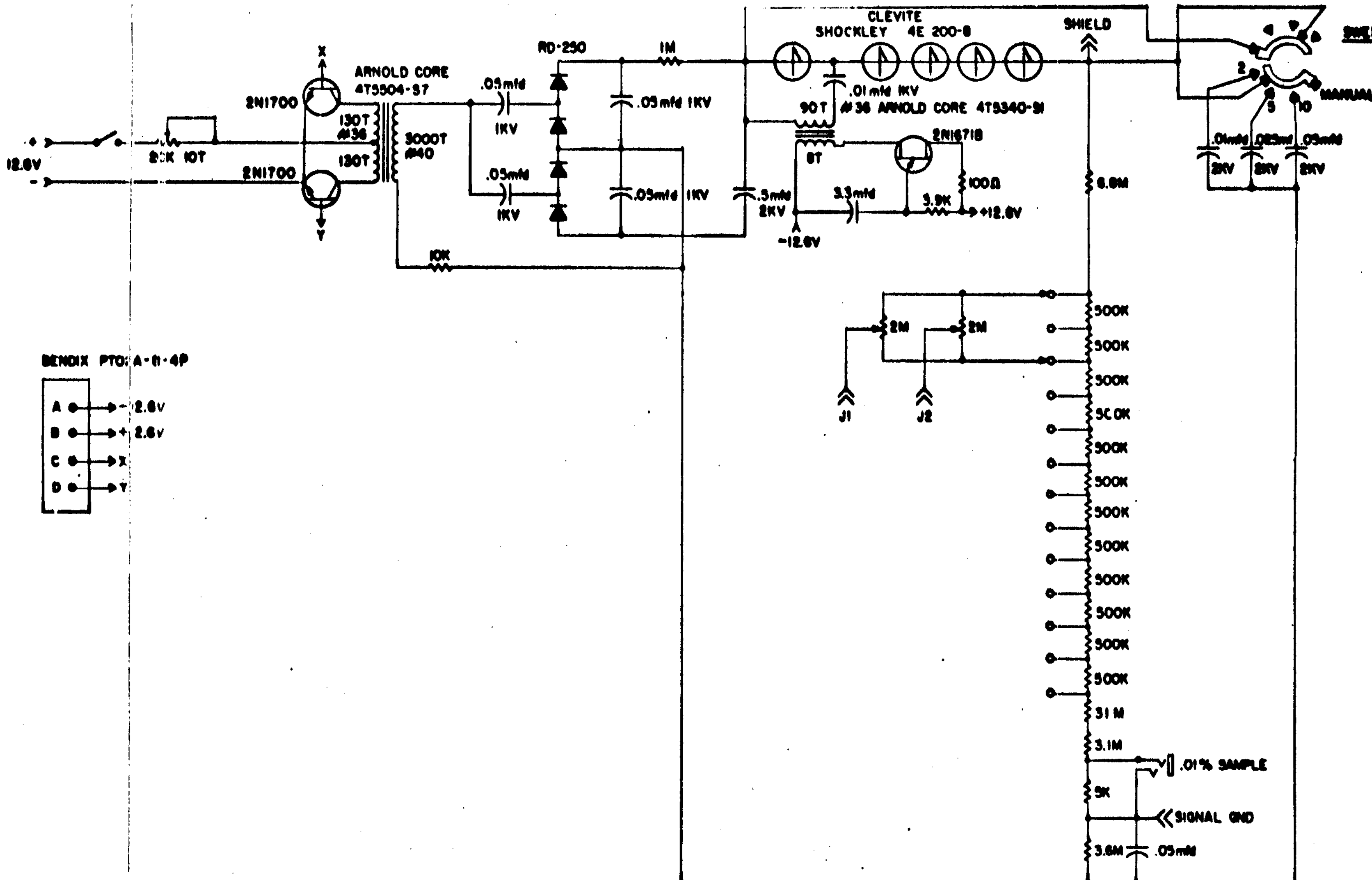

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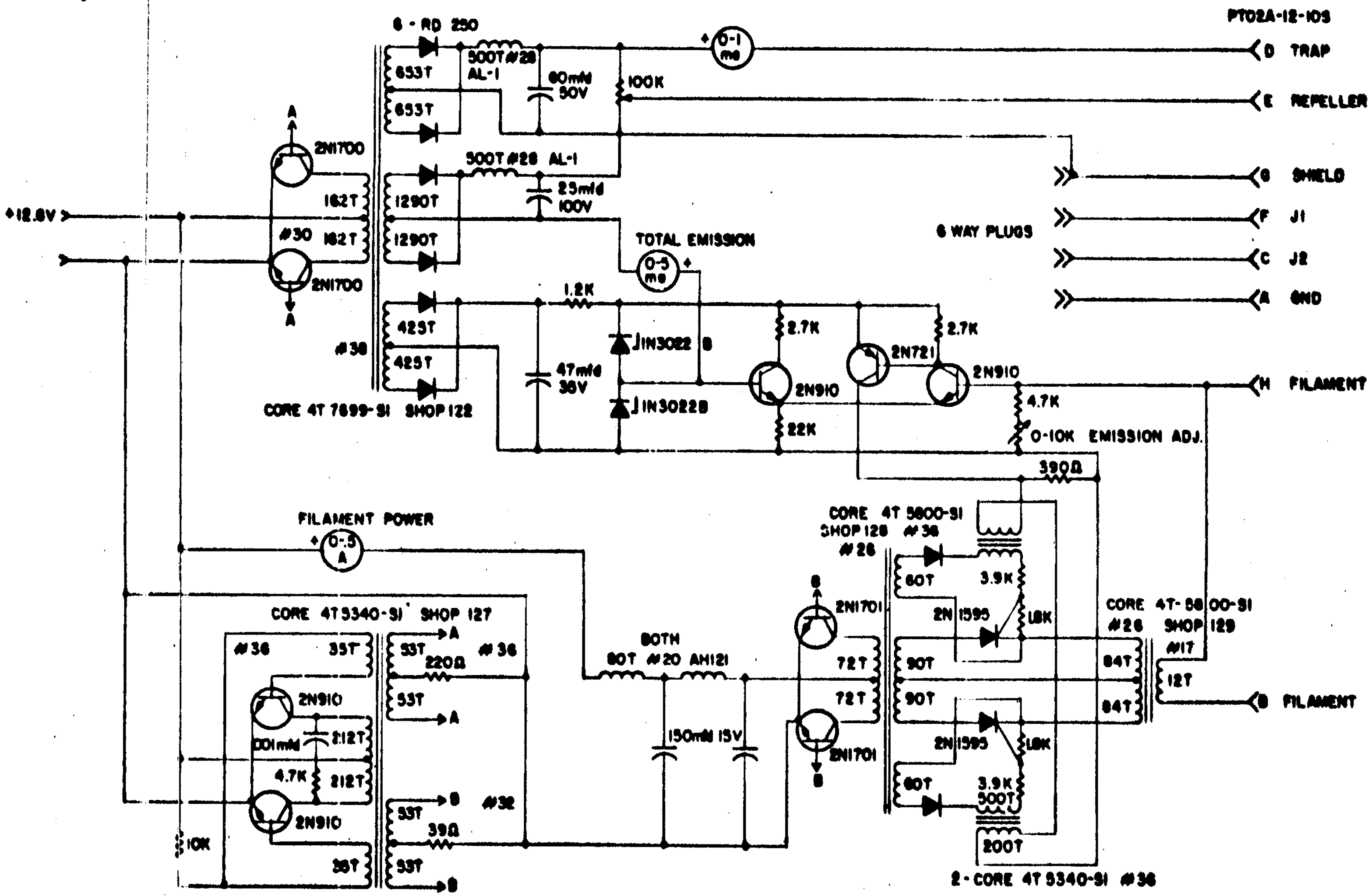
FIG. 15 D

SCHOOL of PHYSICS UNIVERSITY of MINNESOTA

ELECTRONICS SHOP

HIGH VOLTAGE POWER SUPPLY FOR PLANETARY MS

DRAWING NUMBER	DRAWN BY	FOR	CHECKED BY	DATE
E-MS-949 D	JTH	NIER	[illegible]	11-10-62



NOTE: ALL CHOKE & TRANSFORMER CORES ARE ARNOLD ENGINEERING

RE-ORDER No. 62-542

FIG. 15E

SCHOOL of PHYSICS UNIVERSITY of MINNESOTA				
ELECTRONICS SHOP				
EMISSION REGULATOR - LOW POWER				
DRAWING NUMBER	DWN BY	FOR	CHECKED BY	DATE
E-MS-961 A	JTH	NIER	[illegible]	10-29-62
JOB & BUDGET 961-0641-3538-2		CHANGE 1		
		CHANGE 2		
		CHANGE 3		

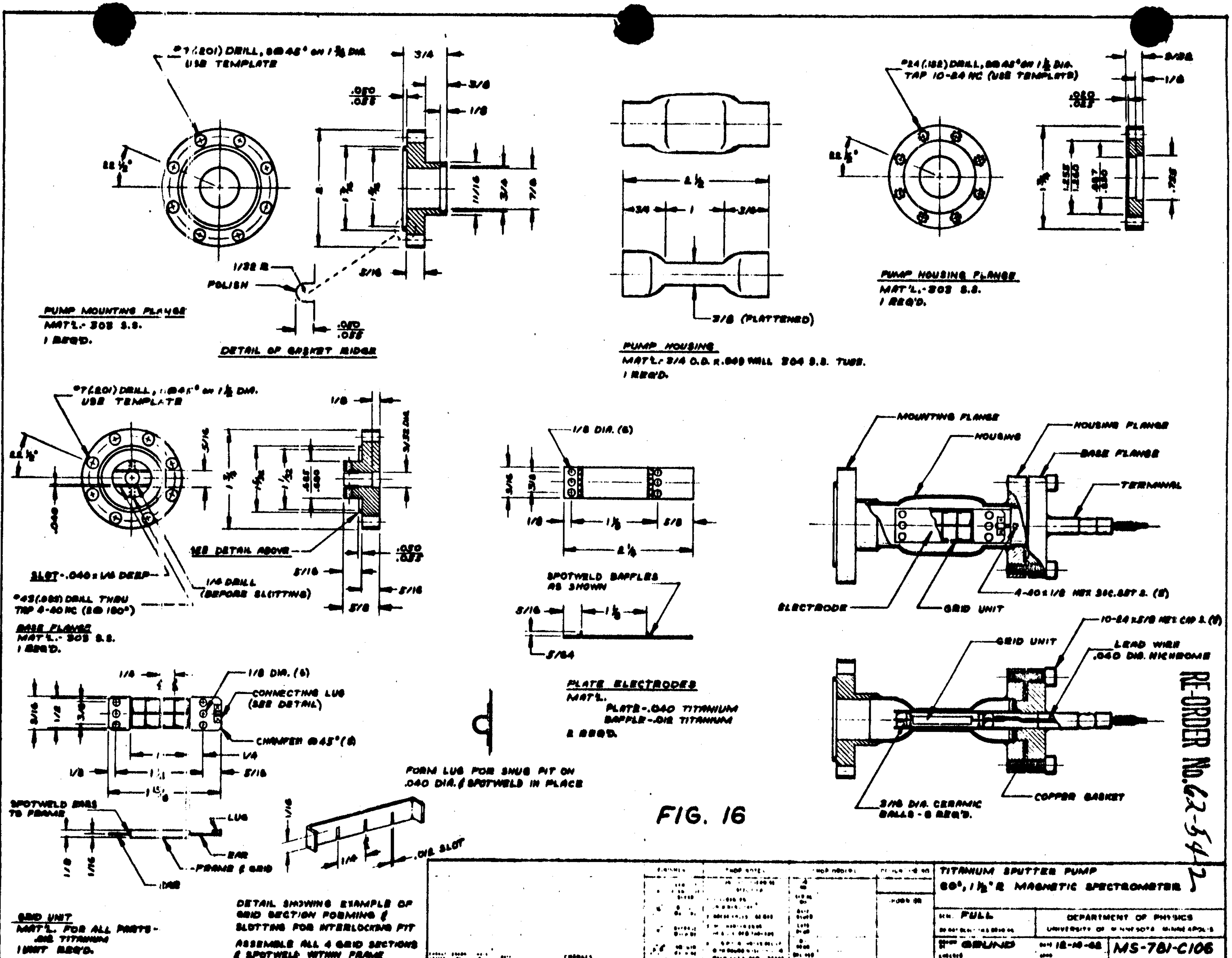

PUMP MOUNTING FLANGE
MAT'L.- 303 S.S.
1 REQ'D.
DETAIL OF GASKET RIDGE
POLISH
1/32 R
PUMP HOUSING
MAT'L.- 3/4 O.D. x .049 WALL 304 S.S. TUBE.
1 REQ'D.
3/8 (FLATTENED)
PUMP HOUSING FLANGE
MAT'L.- 303 S.S.
1 REQ'D.
TAP 10-24 NC (USE TEMPLATE)
USE TEMPLATE
BASE FLANGE
MAT'L.- 303 S.S.
1 REQ'D.
SEE DETAIL ABOVE
1/16 DRILL (BEFORE SLITTING)
1/8 DIA. (6)
SPOTWELD BAFFLES AS SHOWN
PLATE ELECTRODES
MAT'L.
PLATE-.040 TITANIUM
BAFFLE-.012 TITANIUM
2 REQ'D.
MOUNTING FLANGE
HOUSING
HOUSING FLANGE
BASE FLANGE
TERMINAL
ELECTRODE
GRID UNIT
LEAD WIRE
.040 DIA. NICHROME
COPPER GASKET
3/16 DIA. CERAMIC BALLS - 6 REQ'D.
CONNECTING LUG (SEE DETAIL)
CHAMFER @45° (8)
FORM LUG FOR SNUG FIT ON .040 DIA. & SPOTWELD IN PLACE
SPOTWELD BARS TO FRAME
LUG
BAR
FRAME & GRID
.012 SLOT
GRID UNIT
MAT'L. FOR ALL PARTS-.012 TITANIUM
1 UNIT REQ'D.
DETAIL SHOWING EXAMPLE OF GRID SECTION FORMING & SLOTTING FOR INTERLOCKING FIT
ASSEMBLE ALL 4 GRID SECTIONS & SPOTWELD WITHIN FRAME
RE-ORDER No. 62-54-2
TITANIUM SPUTTER PUMP
60°, 1 1/2" R MAGNETIC SPECTROMETER
FULL
DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA MINNEAPOLIS
MS-781-C106

FIG. 16

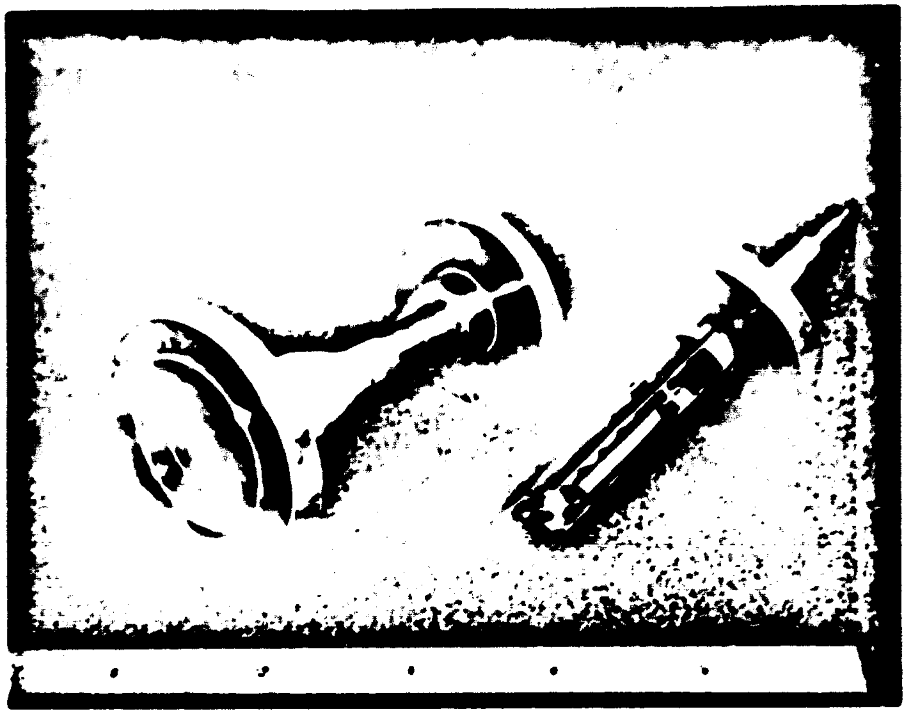


Fig. 17. Photograph of test sputter pump corresponding to drawing shown in Fig. 16.

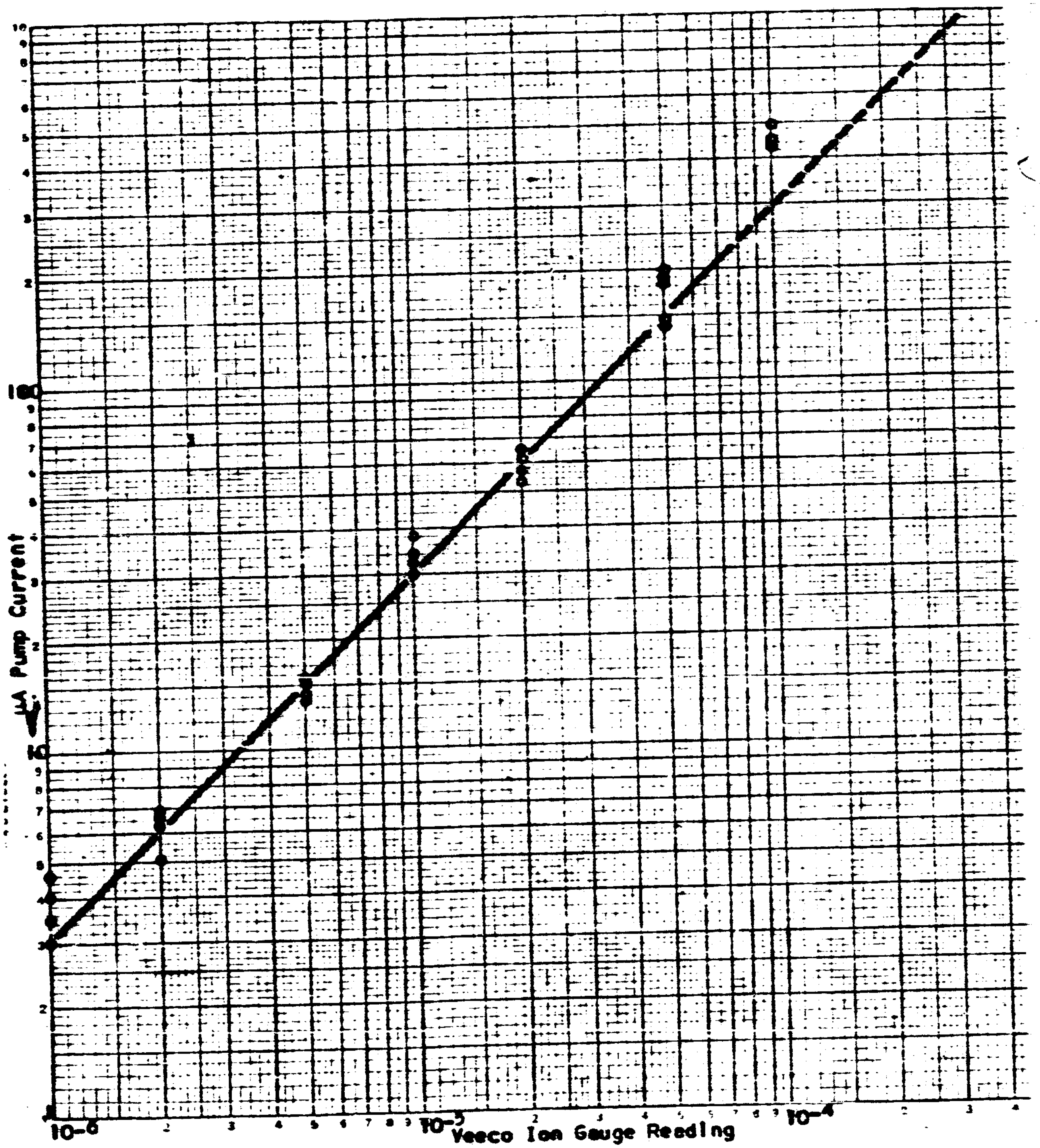


Fig. 18 Sputter pump current versus pressure for air as read by Veeco Ion gauge.